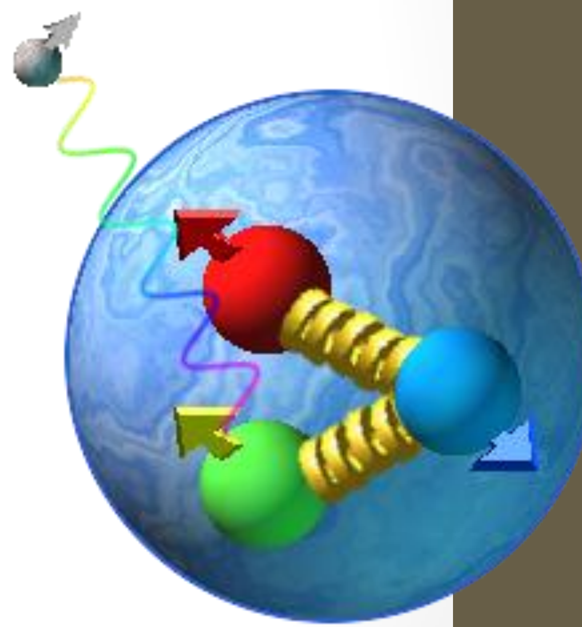
Double spin asymmetry measurement from SANE-HMS data at Jefferson Lab

Hoyoung Kang
For SANE collaboration

Seoul National University
DIS 2013 2013/04/23



Outline

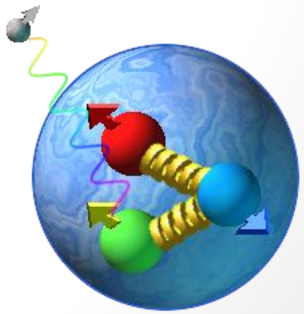
- Introduction to SANE with motivation
- Experimental setup
- Dilution Factor from Packing fraction
- Preliminary HMS Asymmetries
- Summary

SANE - Spin Asymmetries on the Nucleon Experiment

Spin Asymmetries on the Nucleon Experiment, or SANE(TJNAF E07-003), is a measurement of the proton spin asymmetries

done in the Hall C of Thomas Jefferson National Accelerator Facility(Jefferson Lab), Virginia USA

during January-March 2009, excluding installation and commissioning periods.



Spin Structure Functions

Inclusive DIS cross section depends on four structure functions, two unpolarized (F_1, F_2) and two polarized (g_1, g_2). The spin structure functions g_1 and g_2 can be experimentally determined by measuring spin asymmetries:

$$A_{\parallel} = \frac{\sigma^{\downarrow\uparrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\downarrow\uparrow} + \sigma^{\uparrow\uparrow}}, \quad A_{\perp} = \frac{\sigma^{\downarrow\rightarrow} - \sigma^{\uparrow\rightarrow}}{\sigma^{\downarrow\rightarrow} + \sigma^{\uparrow\rightarrow}}.$$

$$g_1(x,Q^2) = \frac{F_1(x,Q^2)}{d'}\left[A_{\parallel} + \tan(\theta/2) A_{\perp}\right],$$

$$g_2(x,Q^2) = \frac{yF_1(x,Q^2)}{2d'}\left[\frac{E + E' \cos(\theta)}{E' \sin(\theta)} A_{\perp} - A_{\parallel}\right]$$

Purpose of SANE

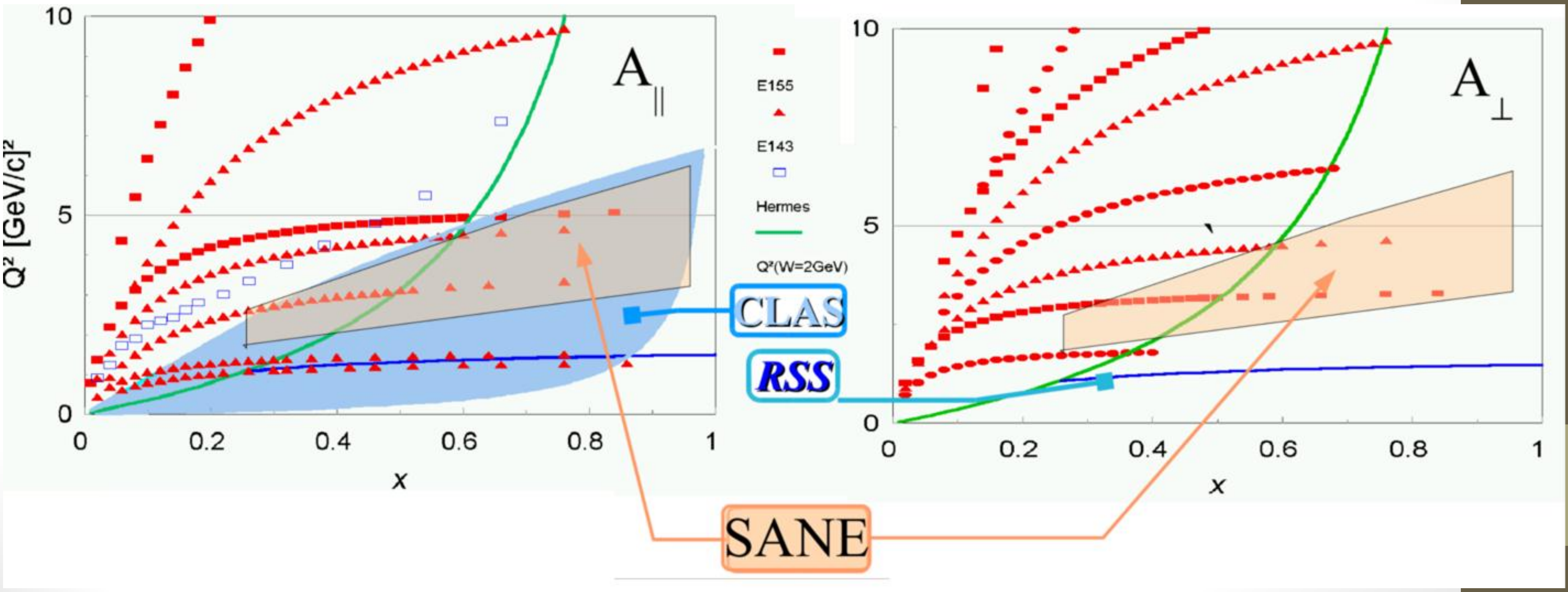
SANE's purpose is to learn everything possible about Proton SSF's from Inclusive Polarized DIS:

- SSF $g_2(x, Q^2)$
- Twist-3 effects (higher twist represents increasing interactions among partons)
- Comparing with lattice QCD, QCD sum rules
- Exploring high Bjorken x region

World Data and SANE Region

World data lacks big region, especially in the perpendicular asymmetry. SANE covers broad region of

$$0.3 \leq x \leq 0.8, \qquad 2.5GeV^2 \leq Q^2 \leq 6.5GeV^2$$



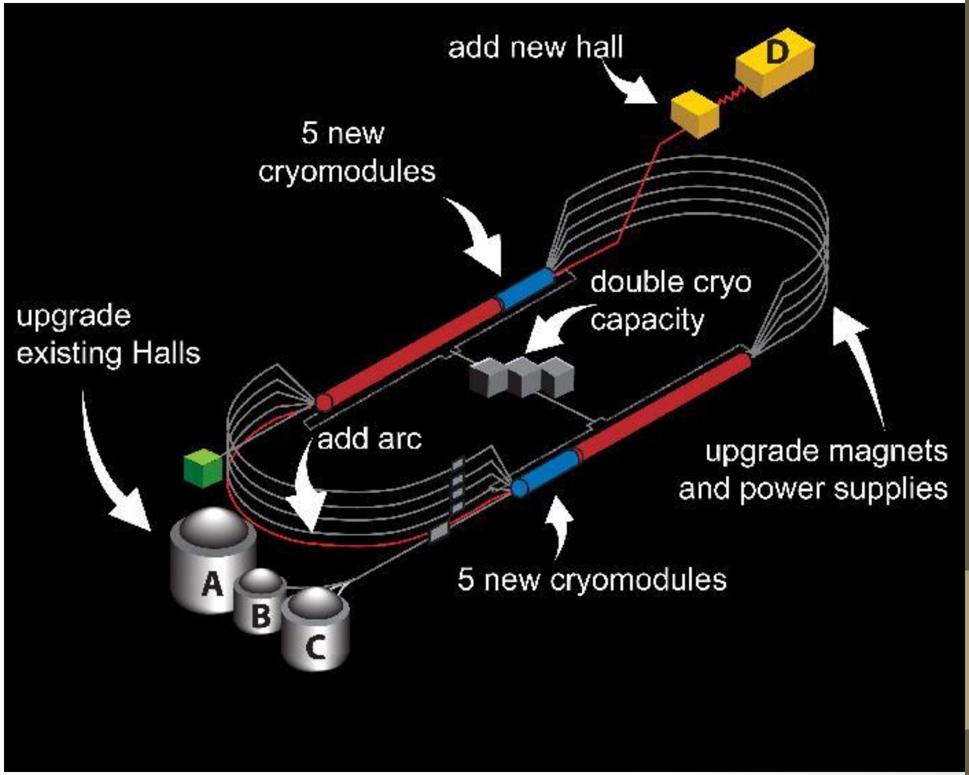
Jefferson Lab CEBAF

Polarized electrons can be accelerated up to 6 GeV and the electron beam is continuous

Two linear accererators and arcs

Up to five pass is available

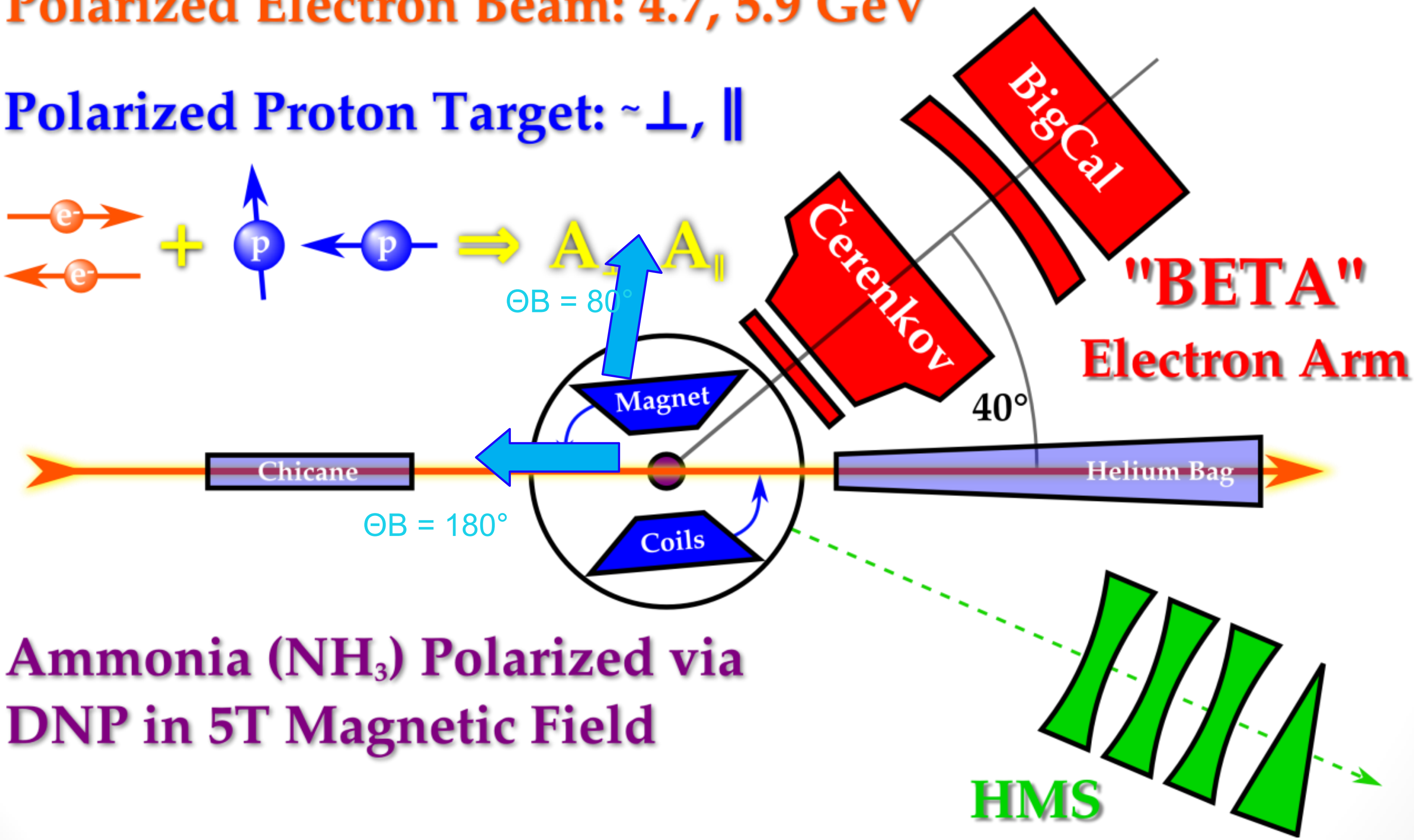
12 GeV upgrade is in progress



Experimental Setup

Polarized Electron Beam: 4.7, 5.9 GeV

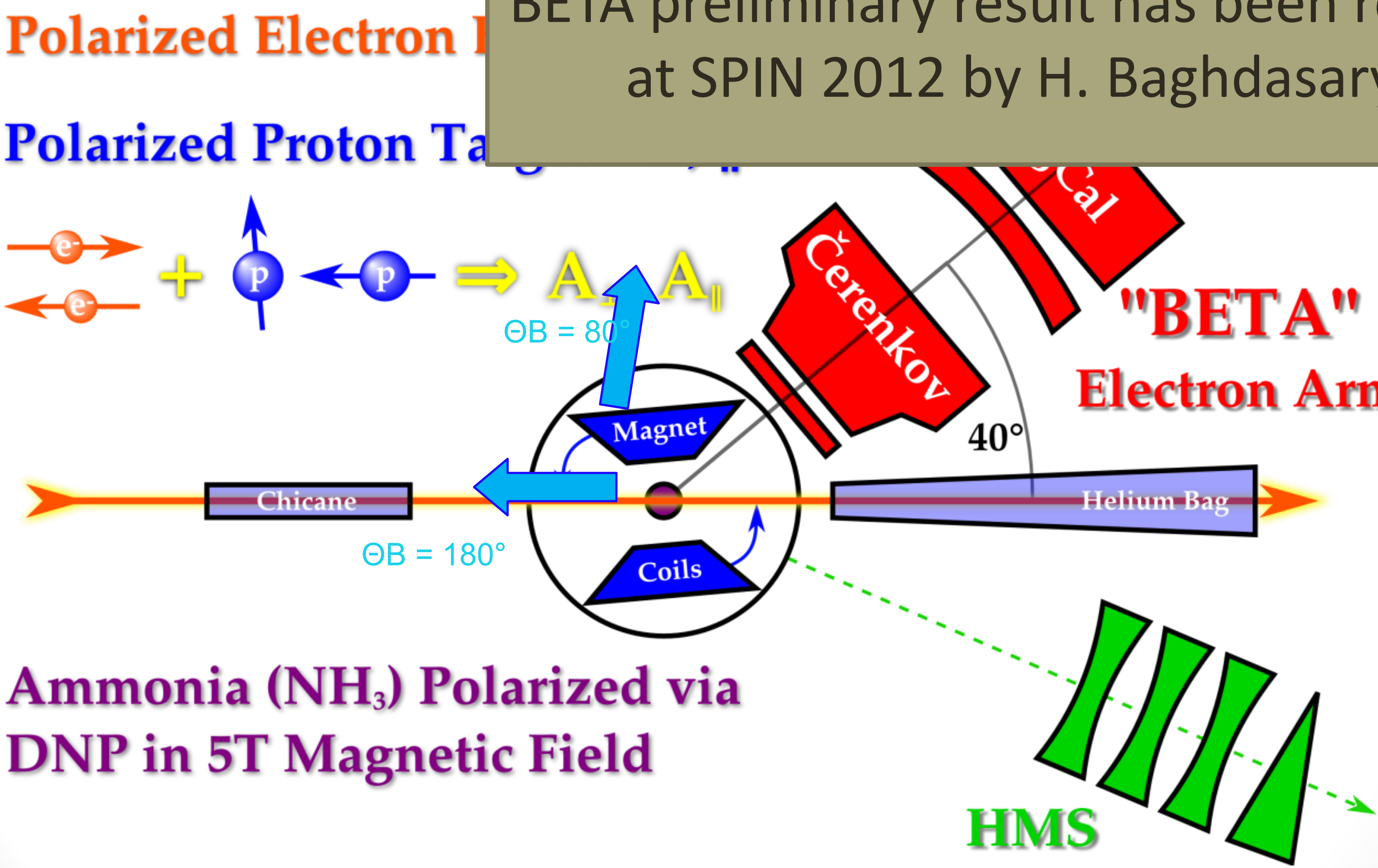
Polarized Proton Target: ~⊥, ||



Ammonia (NH_3) Polarized via DNP in 5T Magnetic Field

Experimental Setup

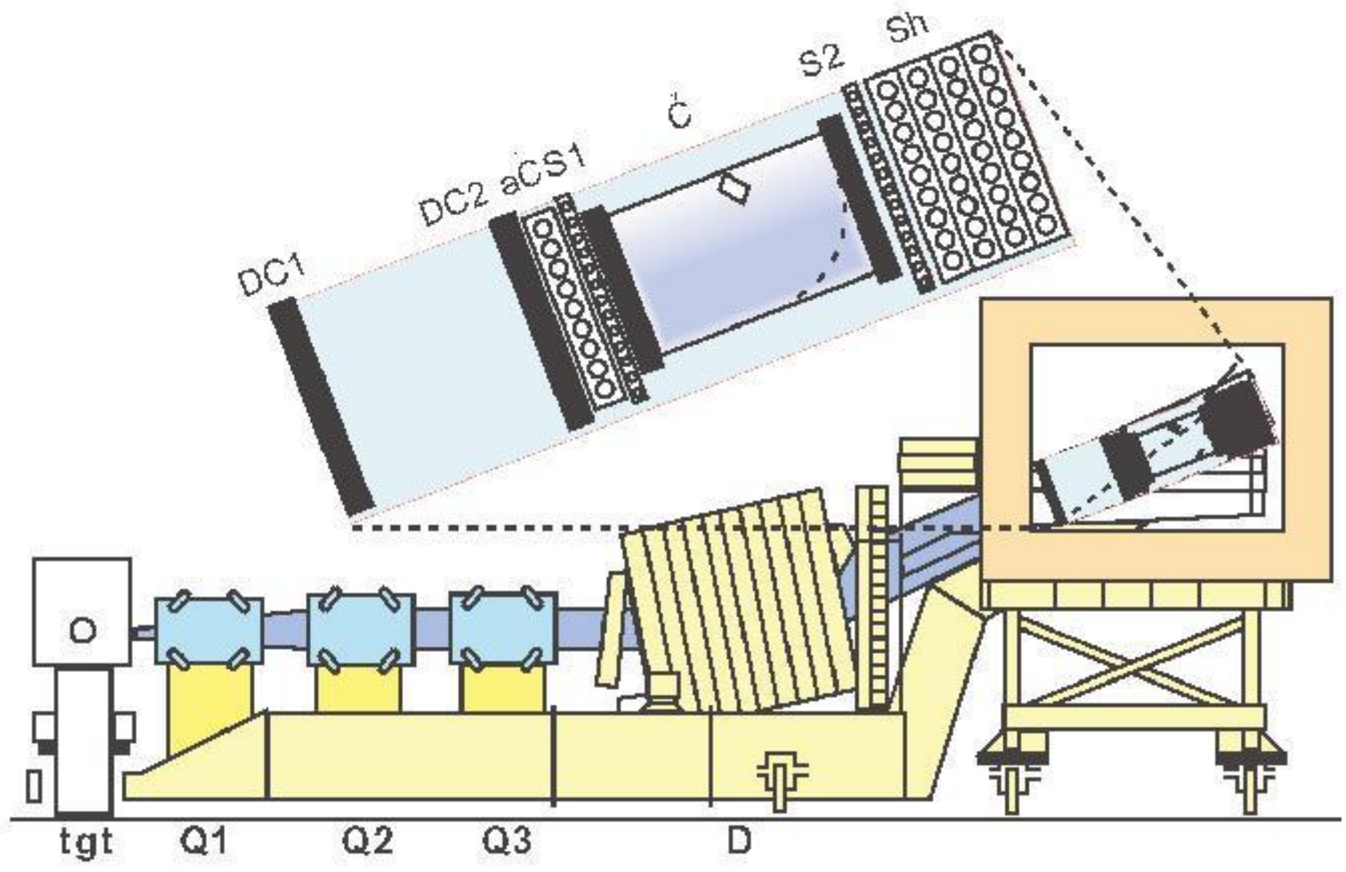
BETA preliminary result has been reported at SPIN 2012 by H. Baghdasaryan



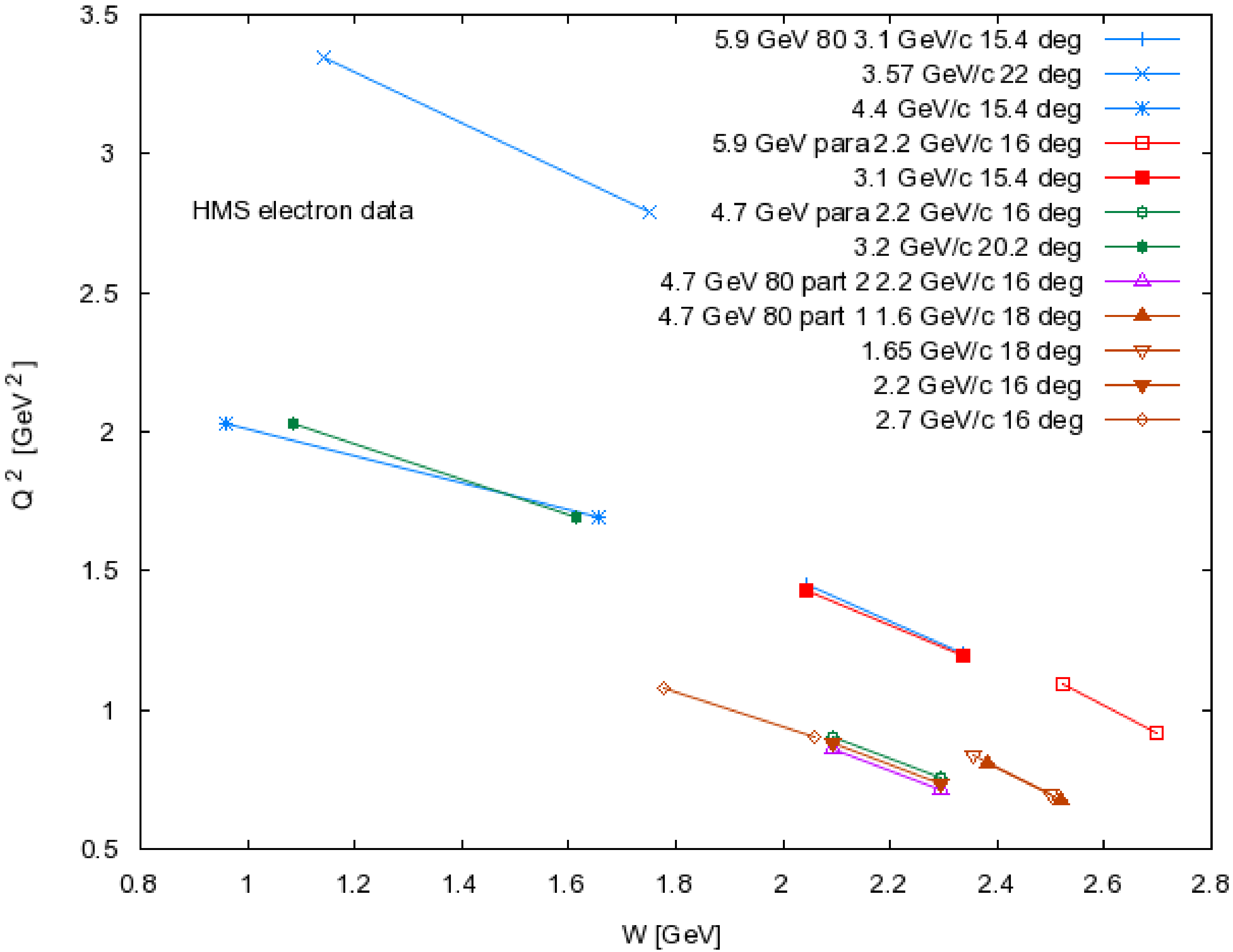
High Momentum Spectrometer

HMS has smaller angular acceptance than BETA, but with precise measurement.
HMS collected complementary data in SANE by varying central angle and momentum.

Resonance Spin Structure(RSS) experiment(2002) have produced meaningful results with limited HMS kinematics and data.
(1.085 GeV< W <1.910 GeV and <Q^2> =1.3 GeV^2)
Phys. Rev. Lett. 105, 101601 (2010)
Phys. Rev. Lett. 98, 132003 (2007)
Phys. Rev. C 74, 035201 (2006)



HMS coverage for SANE



Dilution Factor from Packing Fraction

The target and beam are not completely polarized. It contains also un-polarizable materials.

$$A = \frac{1}{P_b P_t f} \frac{d\sigma^{\downarrow\uparrow} - d\sigma^{\uparrow\uparrow}}{d\sigma^{\downarrow\uparrow} + d\sigma^{\uparrow\uparrow}}$$

Beam Polarization ~80%

Proton(target) Polarization ~70%

Dilution Factor

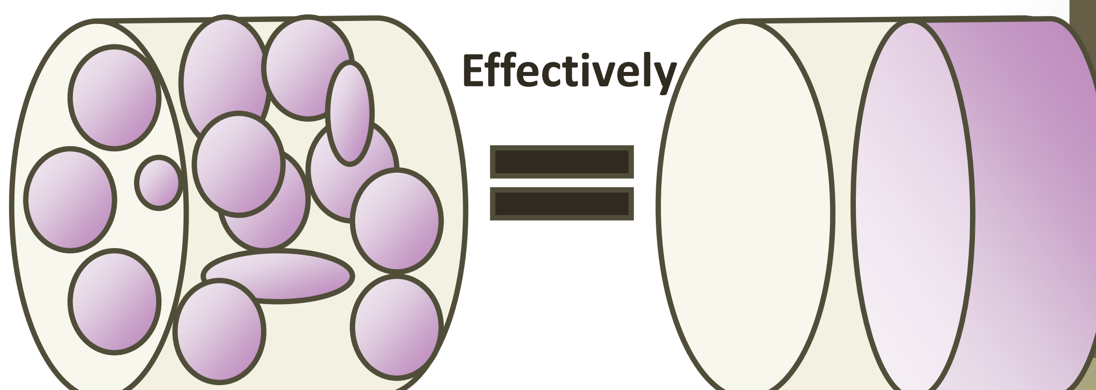
Dilution factor f is the ratio of free polarizable nucleons to the total amount of nucleons in the sample.

$$f = \frac{N_1\sigma_1}{N_1\sigma_1 + N_{14}\sigma_{14} + \sum N_A\sigma_A}$$

where $N_A = \frac{N_0 \varrho_A z_A}{M_A}$

Dilution Factor from Packing Fraction

Packing fraction is the relative volume ratio of ammonia to the target cell, or the fraction of the cell’s length that would be filled with ammonia by cylindrical symmetry.



Dilution Factor from Packing Fraction

Total yield has linear relation with packing fraction:

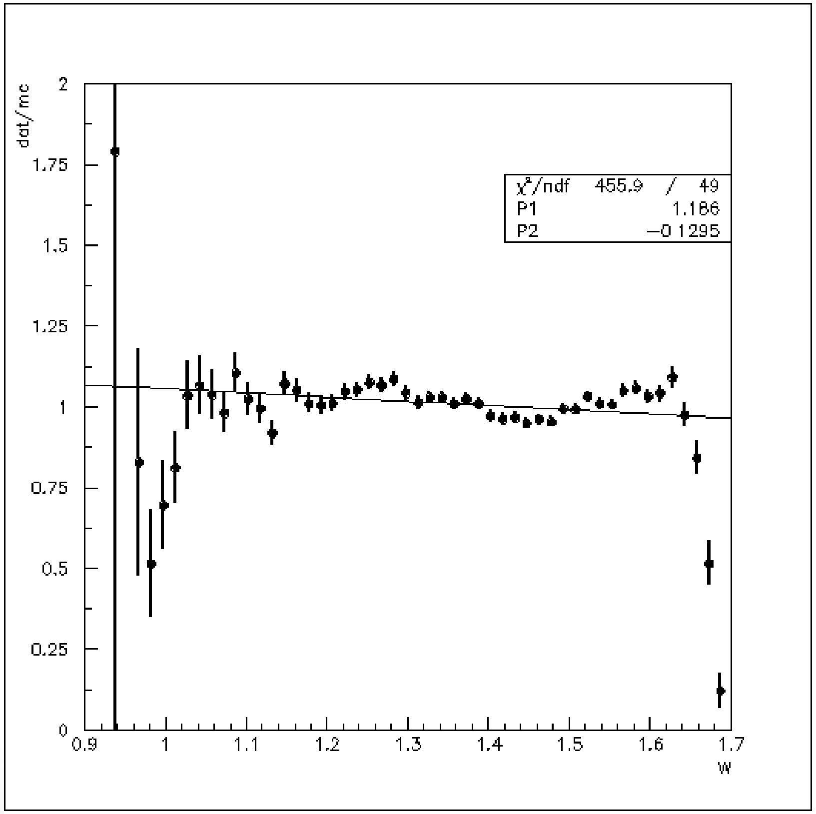
$Y_T = m\,pf + b$

Using MC (P. E. Bosted and M. E. Christy, Phys. Rev., C 77, 065206 (2008)) assuming two different *pf*, the slope(m) and intercept(b) can be calculated and then the yield of real data produces *pf* of real target.

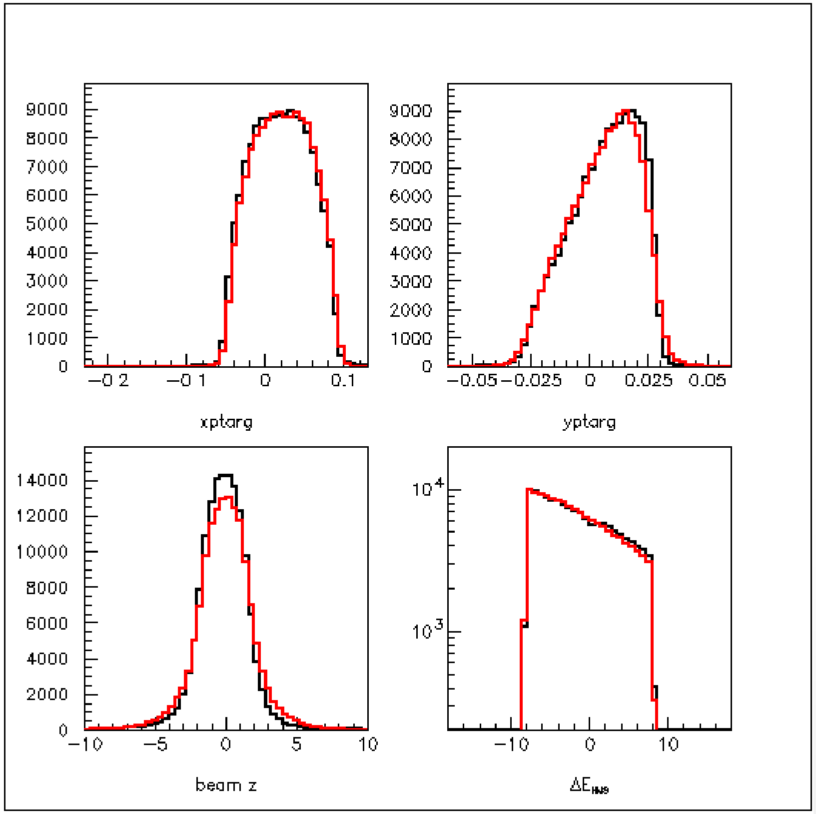
SANE packing fractions are 56% - 62% with ~4.5% error.

Packing fraction

Comparing data with Monte Carlo results assuming 50% and 60% packing fraction of target, 60.9% packing fraction is determined for the target material #9 6-28-07 14NH3.



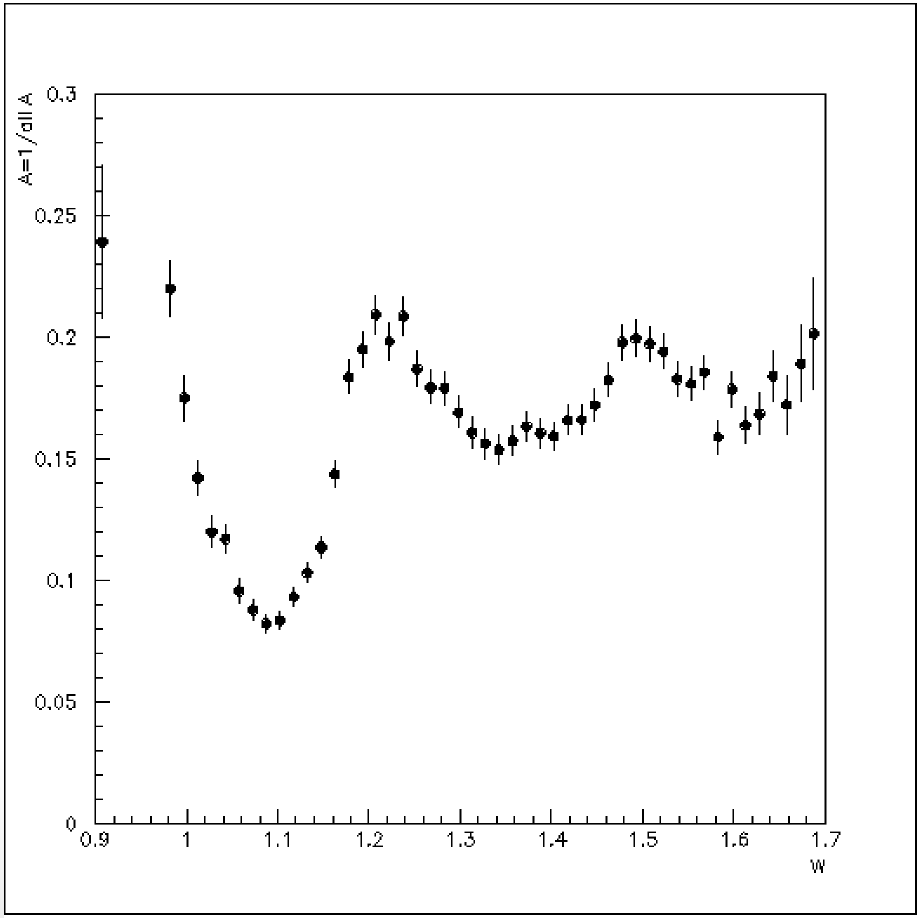
Data to MC ratio (W spectrum)



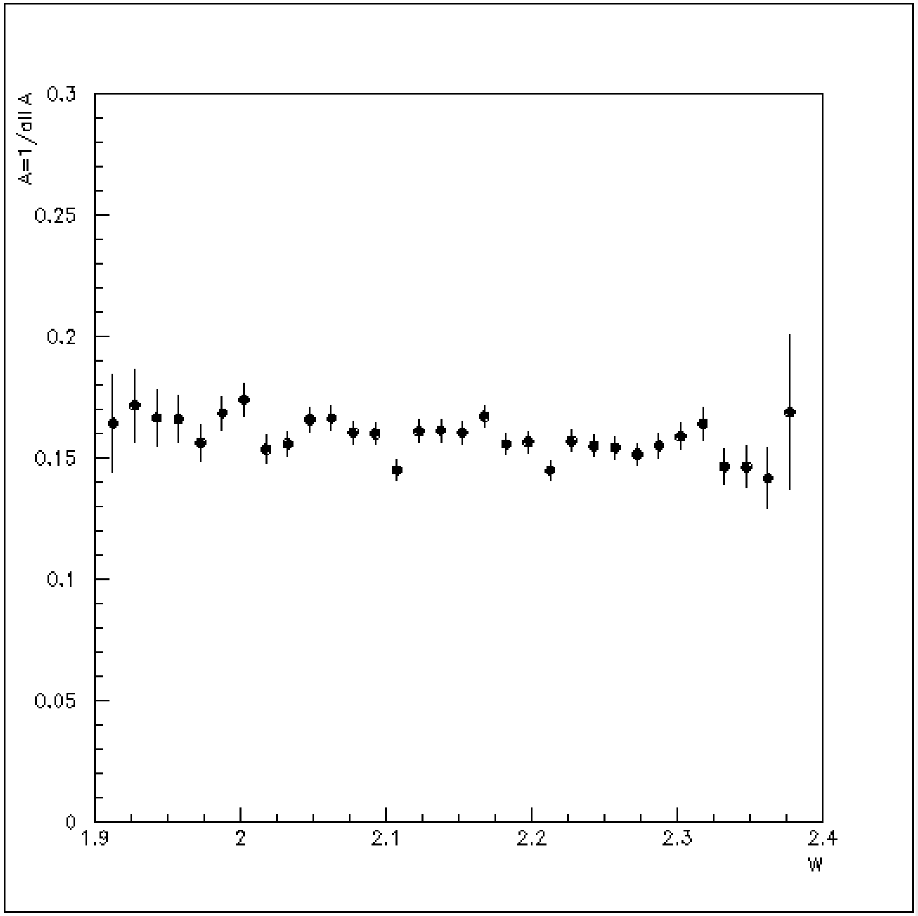
Data and MC comparison (Red is MC)

Dilution factor

Dilution factor is calculated using MC, comparing cross sections of each materials in target cell. And packing fraction is the only necessary input for each target cell.



Dilution factor with PF of 60.9%



Dilution factor with PF of 57.2%

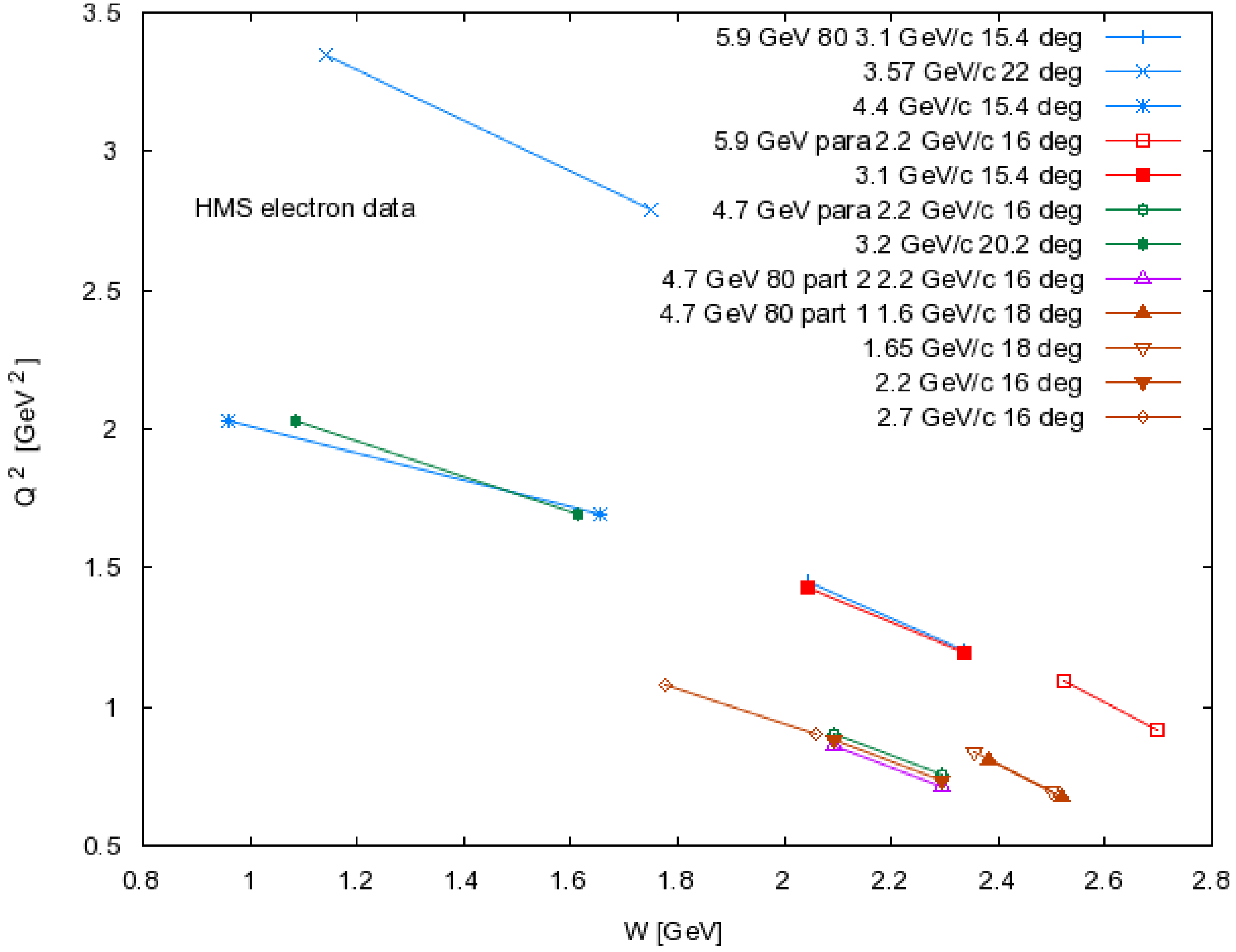
Preliminary Asymmetries

$$A_1 = \frac{1}{D'}\left(\frac{E - E'\cos\theta}{E + E'} A_{180} + \frac{E'\sin\theta}{(E + E')\cos\phi} \frac{A_{180}\cos 80° + A_{80}}{\sin 80°} \right)$$

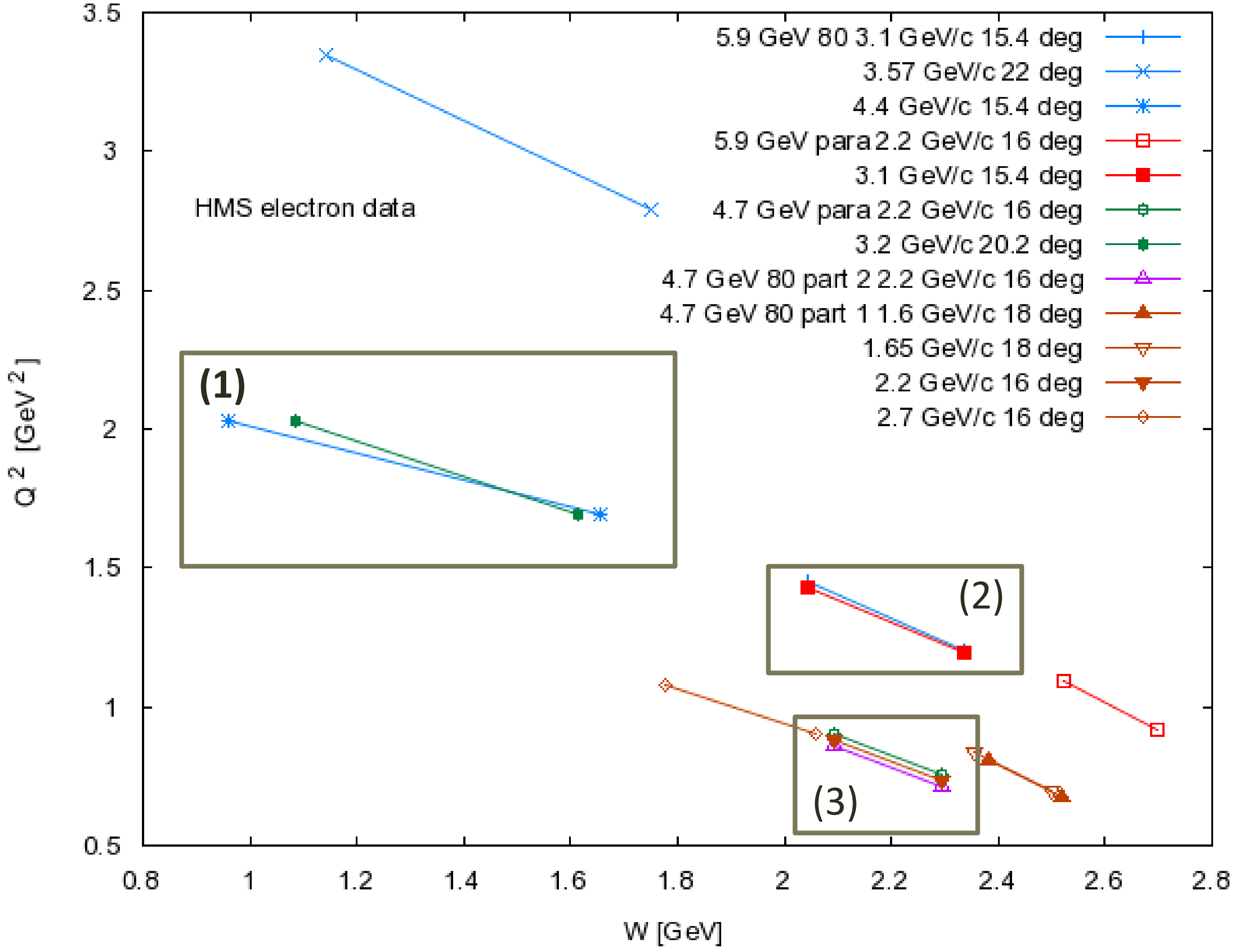
$$A_2 = \frac{1}{D'}\frac{1}{2E}\left(\sqrt{Q^2} A_{180} - \sqrt{Q^2}\frac{E - E'\cos\theta}{E'\sin\theta\cos\phi} \frac{A_{180}\cos 80° + A_{80}}{\sin 80°} \right)$$

Because SANE measured parallel and near-perpendicular asymmetries, careful determination of axis and angle is necessary. To compare SANE result with previous experiment, Resonance Spin Structure (RSS), SANE's perpendicular asymmetry has been defined as a combination of parallel and near-perpendicular asymmetries with sine and cosine factors.

Preliminary Asymmetries



Preliminary Asymmetries

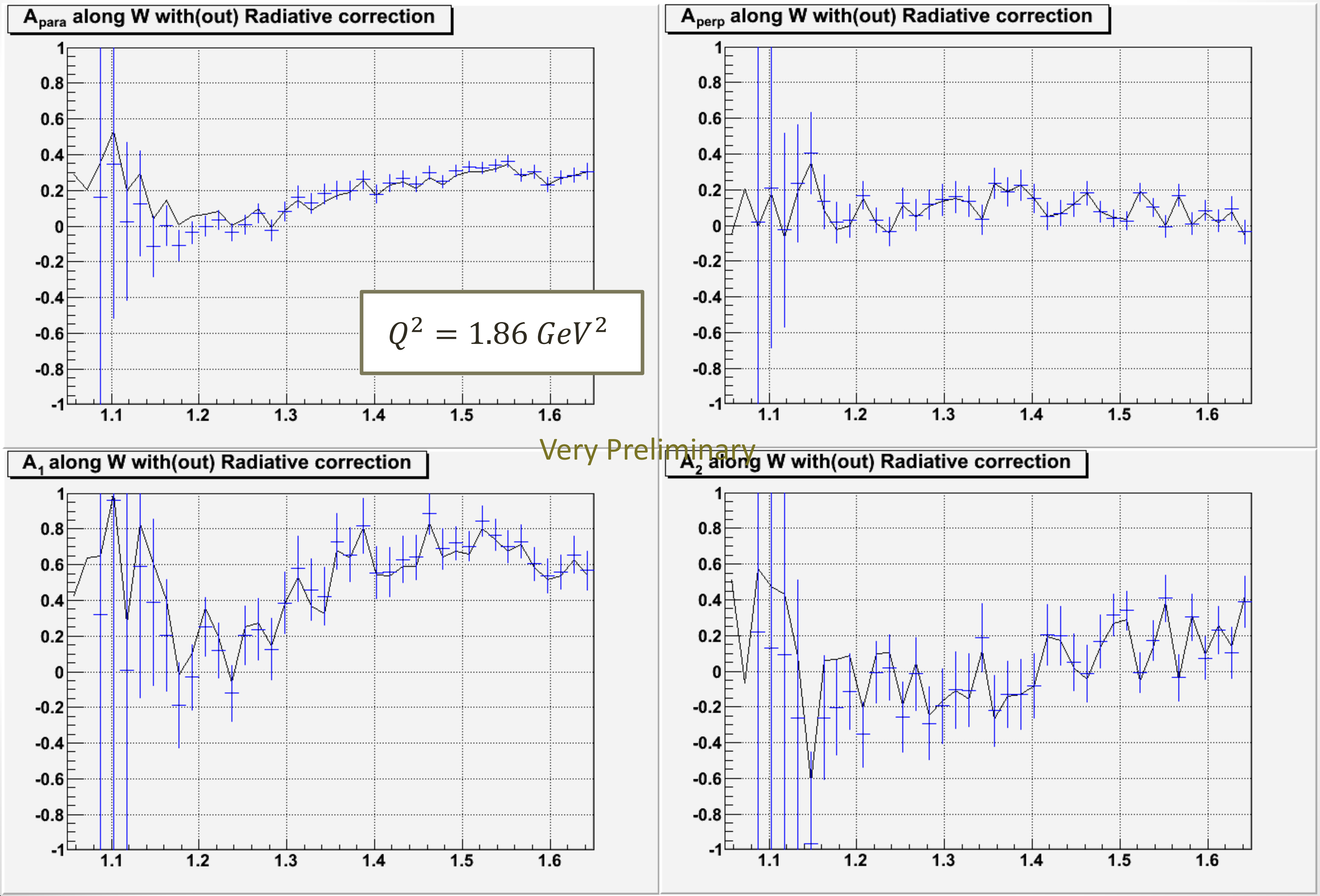


Preliminary Asymmetries

Setting	Beam energy (GeV)	HMS central momentum (GeV)	HMS angle from beamline (degree)	$< Q^2 >$ (GeV^2)	$< W >$ (GeV)
(1)	4.7 (par) / 5.9 (per)	3.2 (par) / 4.4 (per)	20.2 (par) / 15.4 (per)	1.863	1.353
(2)	5.9	3.1	15.4	1.313	2.196
(3)	4.7	2.2	16	0.806	2.196

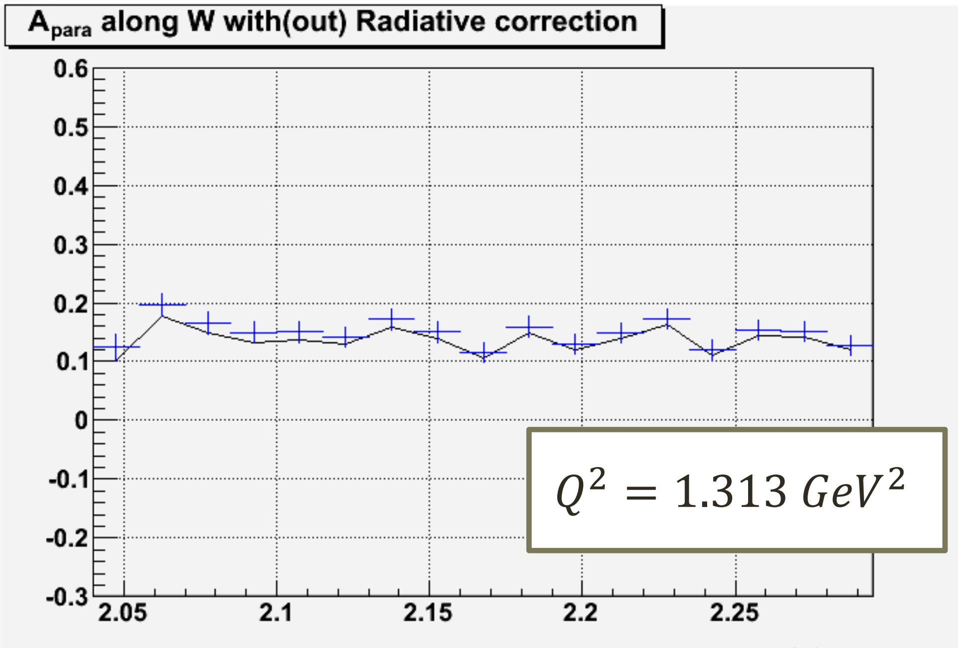
Preliminary Asymmetries (1)

Blue is with radiative correction / only statistical error included

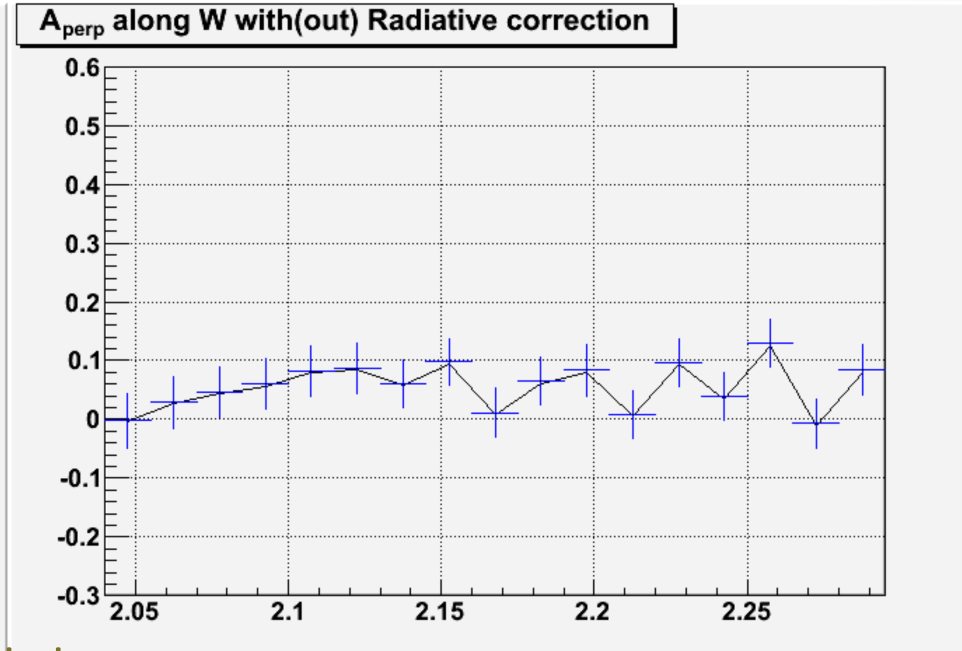


Preliminary Asymmetries (2)

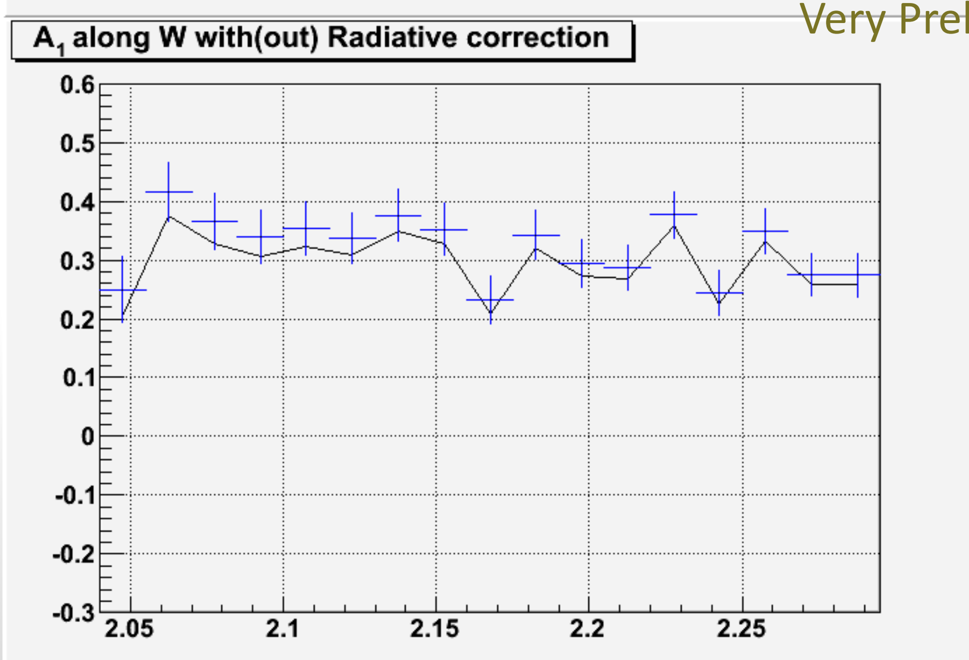
Blue is with radiative correction / only statistical error included

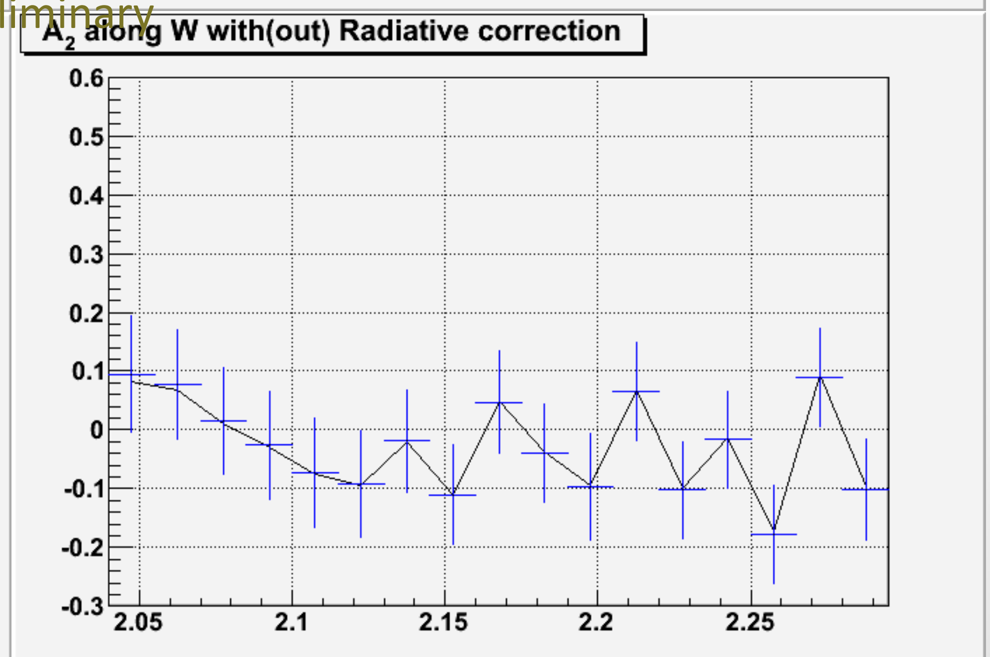


$$Q^2 = 1.313\ GeV^2$$



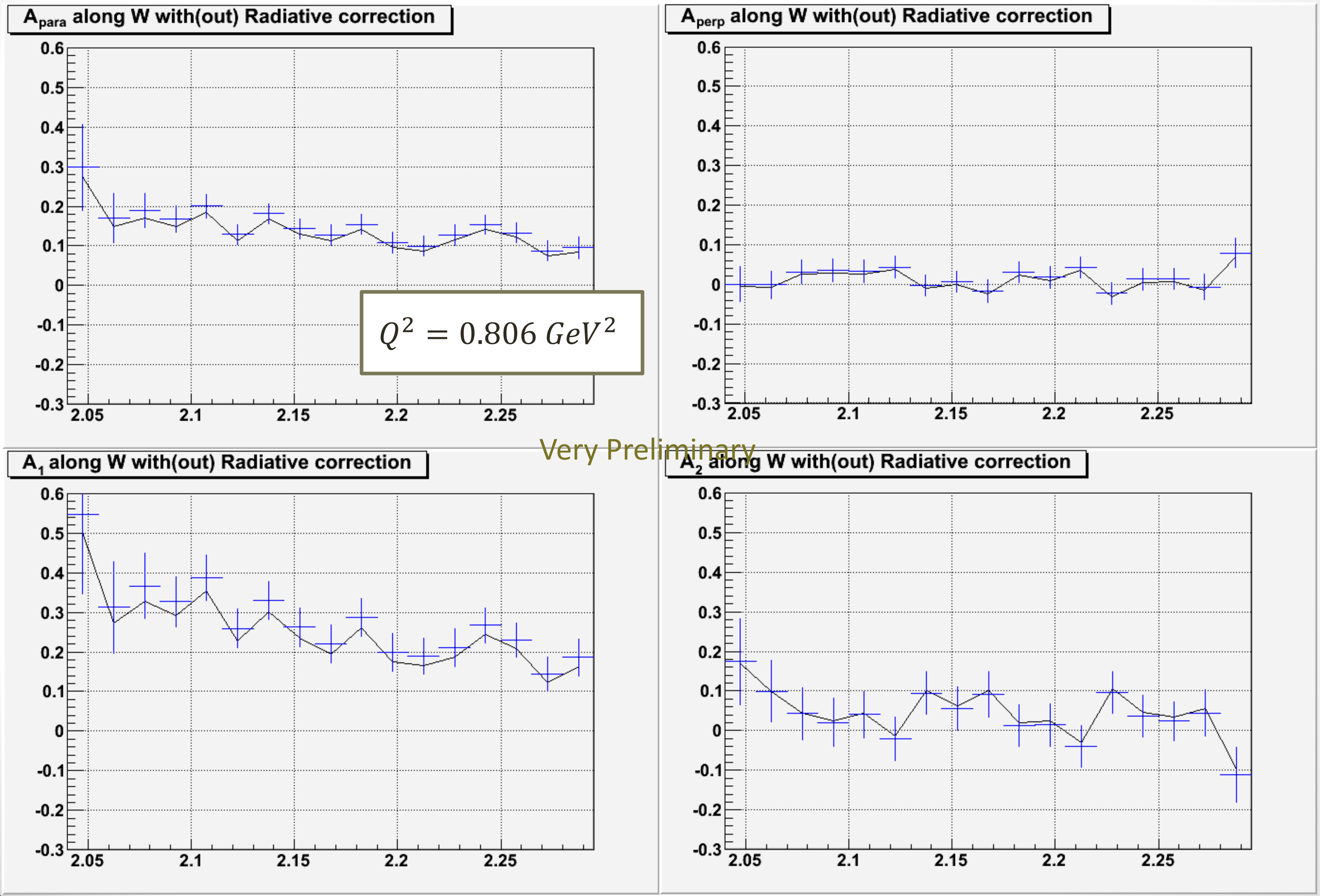
Very Preliminary



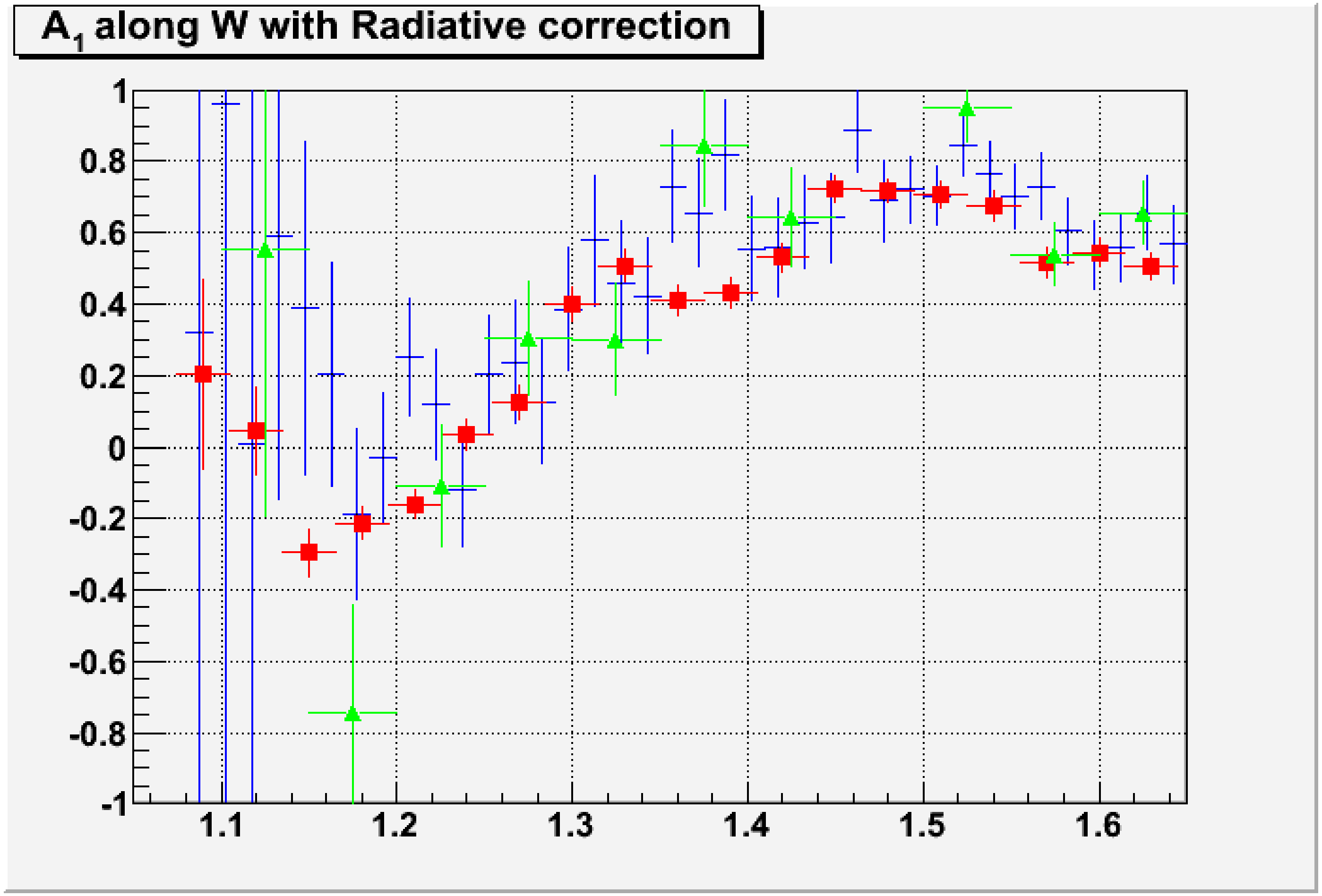


Preliminary Asymmetries (3)

Blue is with radiative correction / only statistical error included

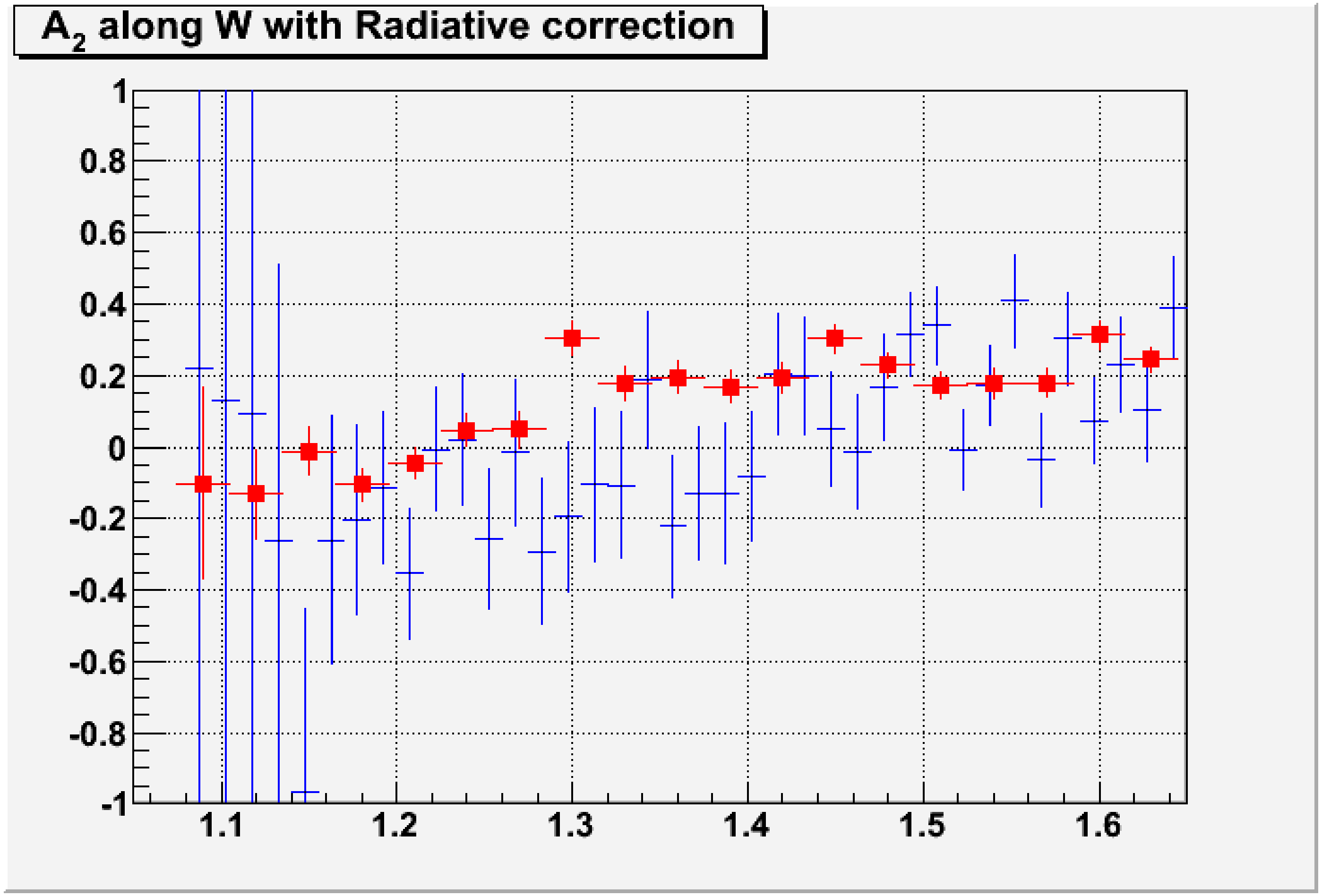


Preliminary Asymmetries



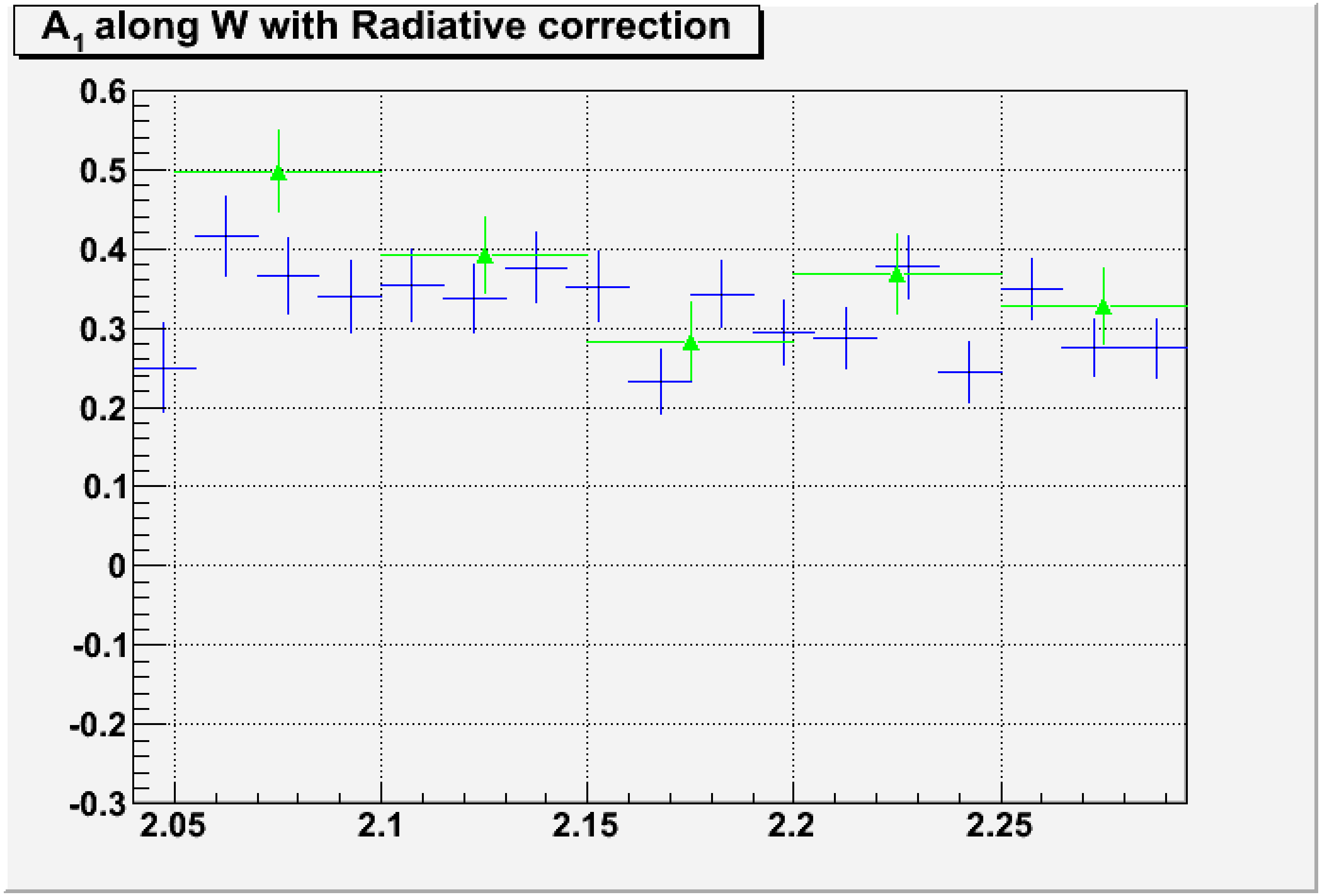
- Green triangles : CLAS EG1b result with Q^2 = 1.71 GeV^2
- Red squares : RSS result with Q^2 = 1.3 GeV^2
- Blue line : This work with Q^2 = 1.86 GeV^2

Preliminary Asymmetries



Red squares : RSS result with $Q^2 = 1.3\ GeV^2$
Blue line : This work with $Q^2 = 1.86\ GeV^2$

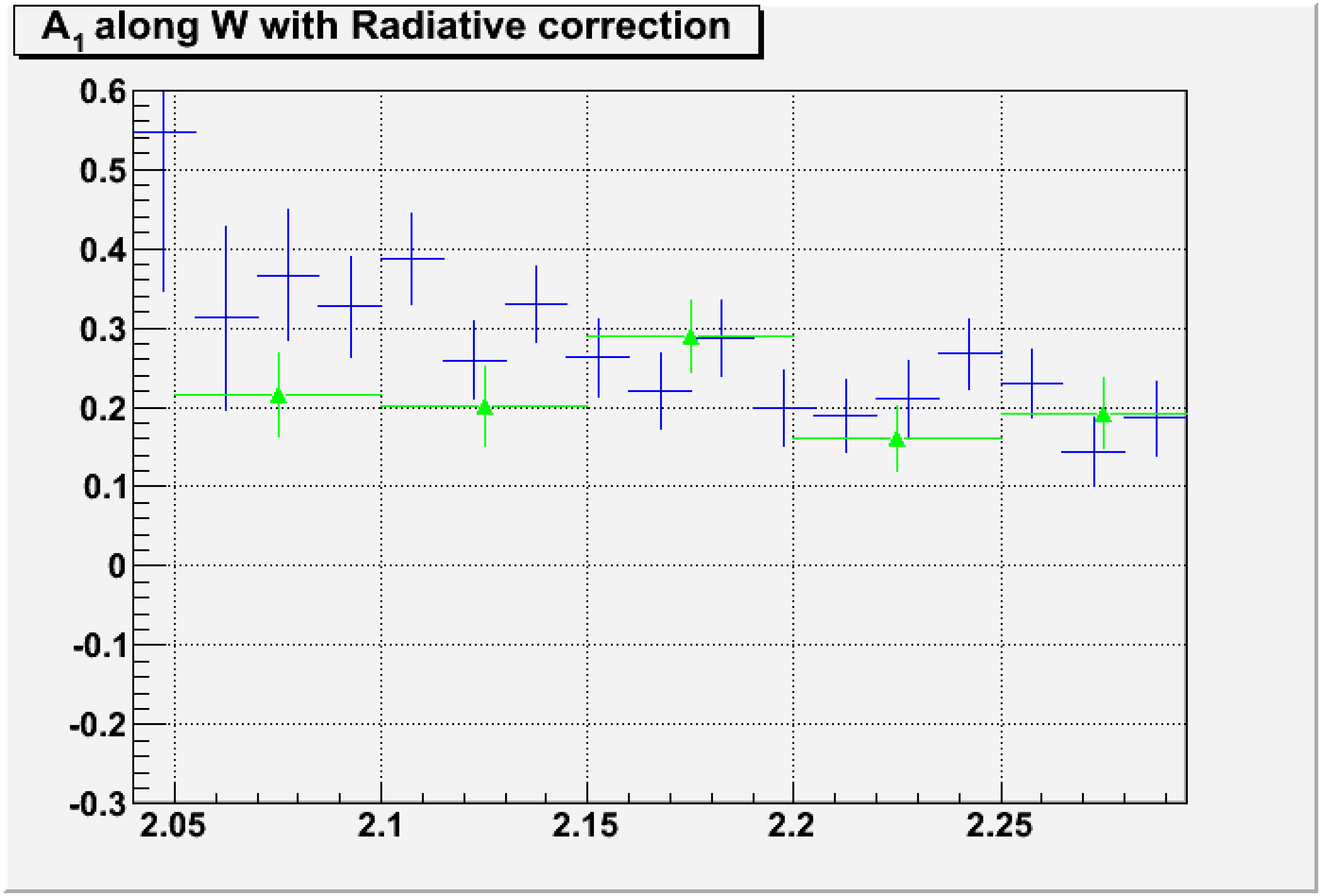
Preliminary Asymmetries



Green triangles : CLAS EG1b result with $Q^2 = 1.2\ GeV^2$

Blue line : This work with $Q^2 = 1.313\ GeV^2$

Preliminary Asymmetries



- Green triangles : CLAS EG1b result with $Q^2 = 0.844\ GeV^2$
- Blue line : This work with $Q^2 = 0.806\ GeV^2$

SANE collaboration

U. Basel, Florida International U., Hampton U., Norfolk S. U., North Carolina A&T S. U., IHEP-Protvino, U. of Regina, Rensselaer Polytechnic I., Rutgers U., Seoul National U., Temple U., TJNAF, U. of Virginia, College of William & Mary, Yerevan Physics I.

Spokespersons: S. Choi (Seoul), M. Jones(Jlab), Z-E. Meziani (Temple), O. A. Rondon (U. of Virginia)

Summary

- SANE is a measurement of spin structure functions in broad range of Bjorken x and Q^2.
- HMS data covers various kinematic regions and it can produce meaningful results, besides BETA(main detector) data.
- Using HMS data, dilution factor of each target cell is obtained.
- Preliminary parallel and perpendicular asymmetries shows good agreement with previous experiments.

Backup slides

Experimental goal

The goal is to get the proton spin structure functions g_1 and g_2 over broad range of

the Bjorken scaling variable

$$0.3 \leq x \leq 0.8$$

and 4-momentum transfer

$$2.5 GeV^2 \leq Q^2 \leq 6.5 GeV^2$$

ep deep inelastic scattering

Invariant quantities:

$\nu = \frac{q \cdot P}{M} = E - E'$ is the lepton's energy loss in the nucleon rest frame (in earlier literature sometimes $\nu = q \cdot P$). Here, E and E' are the initial and final lepton energies in the nucleon rest frame.

$Q^2 = -q^2 = 2(EE' - \vec{k} \cdot \vec{k}') - m_\ell^2 - m_{\ell'}^2$ where $m_\ell(m_{\ell'})$ is the initial (final) lepton mass. If $EE' \sin^2(\theta/2) \gg m_\ell^2, m_{\ell'}^2$, then

$\approx 4EE' \sin^2(\theta/2)$, where θ is the lepton's scattering angle with respect to the lepton beam direction.

$x = \frac{Q^2}{2M\nu}$ where, in the parton model, x is the fraction of the nucleon's momentum carried by the struck quark.

$y = \frac{q \cdot P}{k \cdot P} = \frac{\nu}{E}$ is the fraction of the lepton's energy lost in the nucleon rest frame.

$W^2 = (P + q)^2 = M^2 + 2M\nu - Q^2$ is the mass squared of the system X recoiling against the scattered lepton.

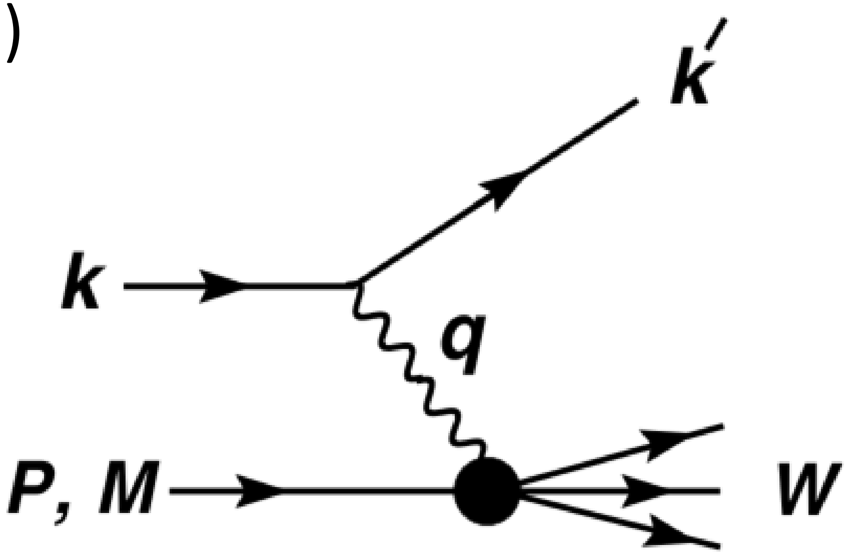
C. Amsler et al., Physics Letters B667, 1 (2008)

ep deep inelastic scattering

High-energy electron-nucleon scattering(Deep Inelastic Scattering) ep → e’X

k and k’ are the four-momenta of the incoming and outgoing electrons, P is the four-moemntum of a proton with mass M, and W is the mass of the recoiling system X.

q is the four-momentum of the virtual photon(the exchanged particle). ($Q^2 = -q^2$)



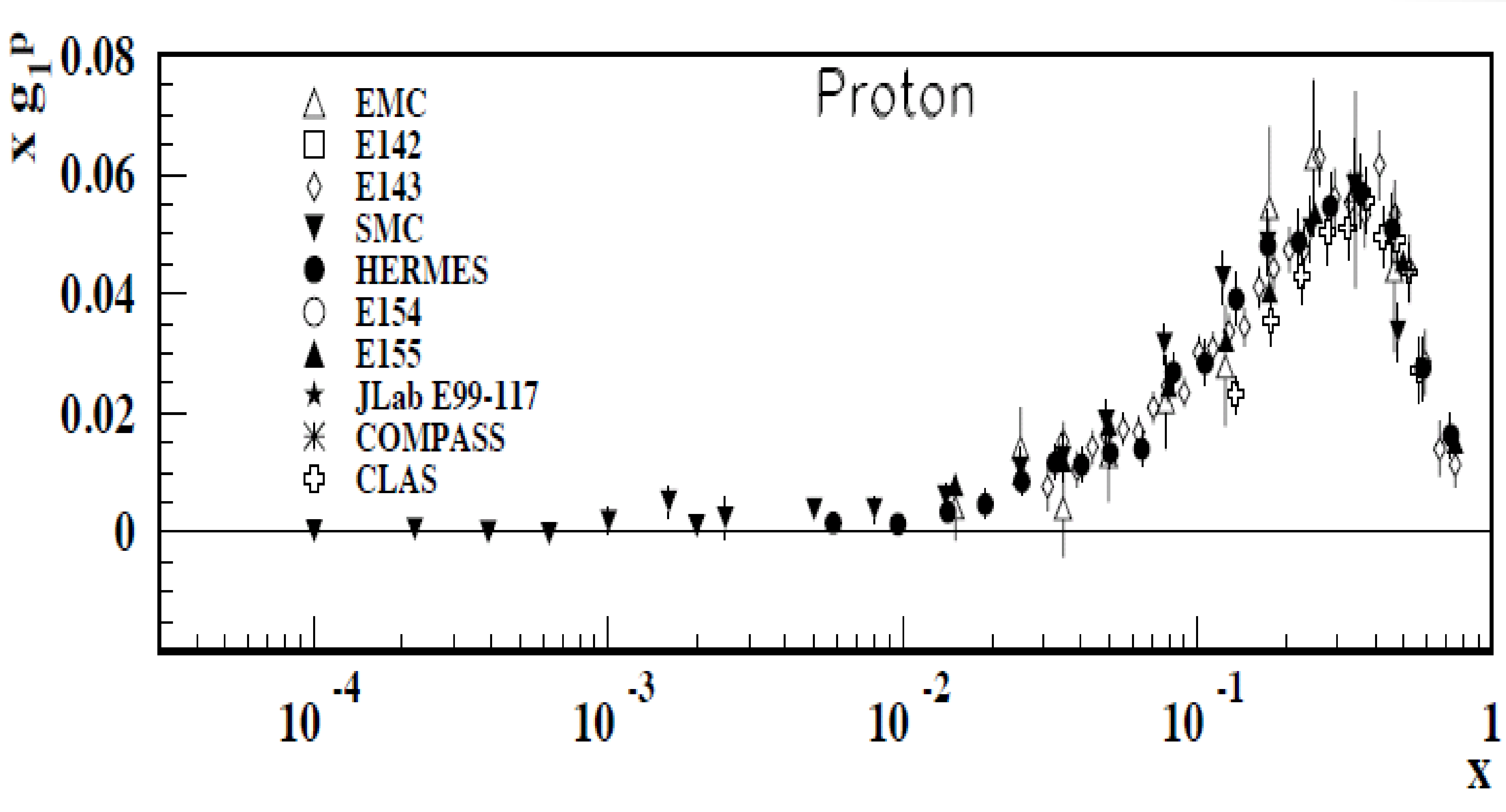
Spin structure functions

When the spins of electron and nucleon are all polarized, we can see the dependence of scattering cross section on the spin structure functions $g_1(x, Q^2)$ and $g_2(x, Q^2)$.

$$g_1 = \frac{1}{2}\sum_i e_i^2[q_i^+ - q_i^-]$$

$$g_2 = g_2^{WW} + \overline{g_2}$$

World Data of g_1



C. Amsler et al., Physics Letters B667, 1 (2008)

Jefferson Lab

Thomas Jefferson National Accerator Facility

Located in Newport News, Virginia, USA

Funded by the U.S. Department of Energy's Office of Science

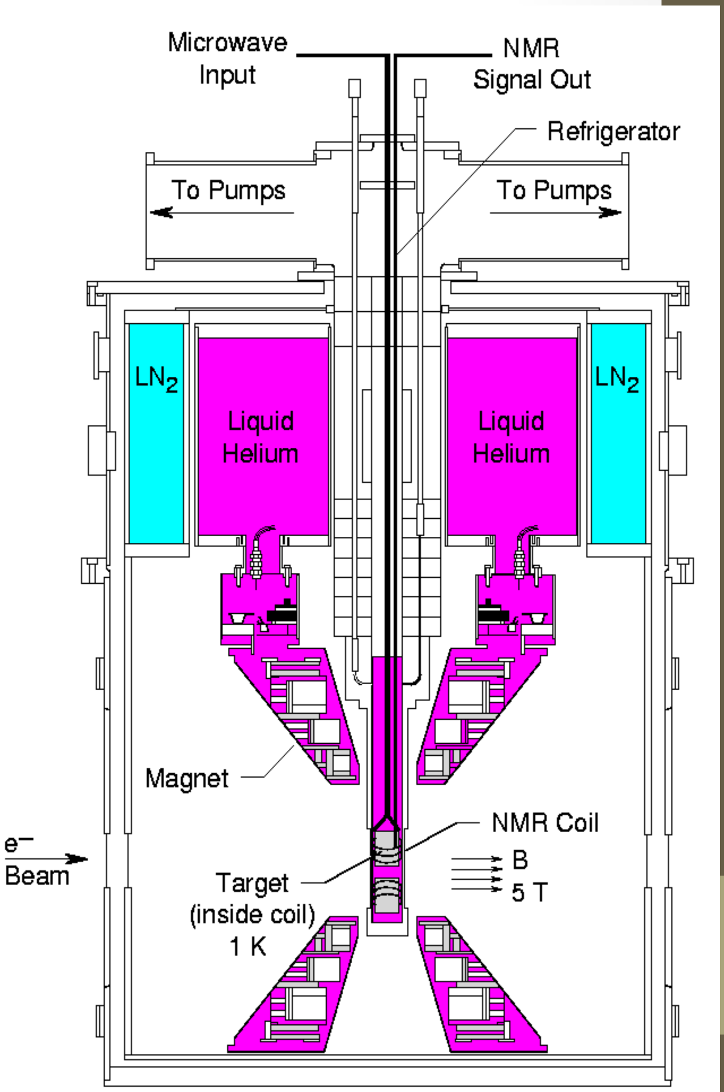
Having CEBAF (Continuous Electron Beam Accelerator Facility) and three experimental halls

UVA Target

Superconducting magnet applies 5-T magnetic field.

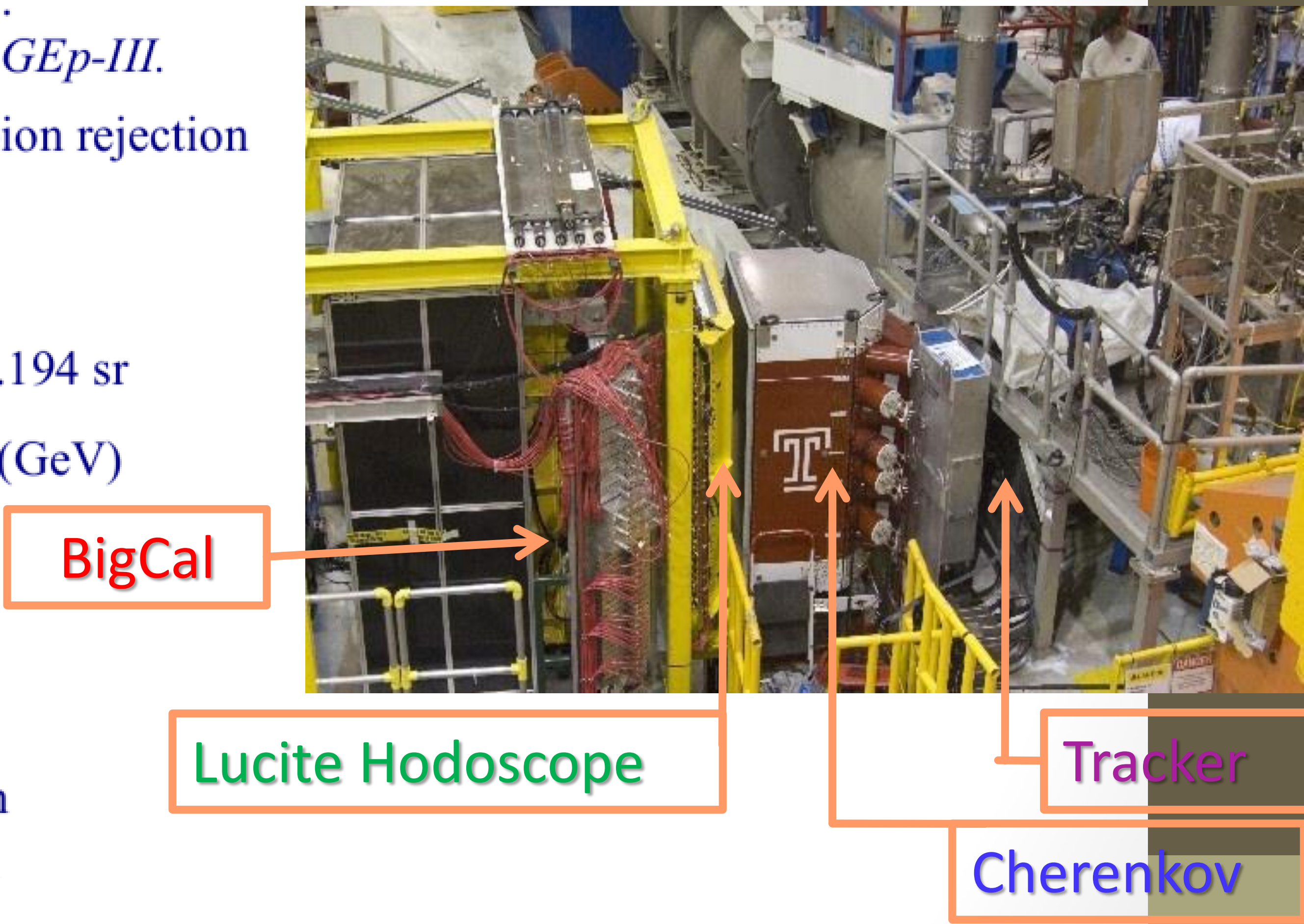
The target and the magnet are cooled down by liquid helium.

~140 Ghz microwave frequency causes dynamic nuclear polarization up to 90%.

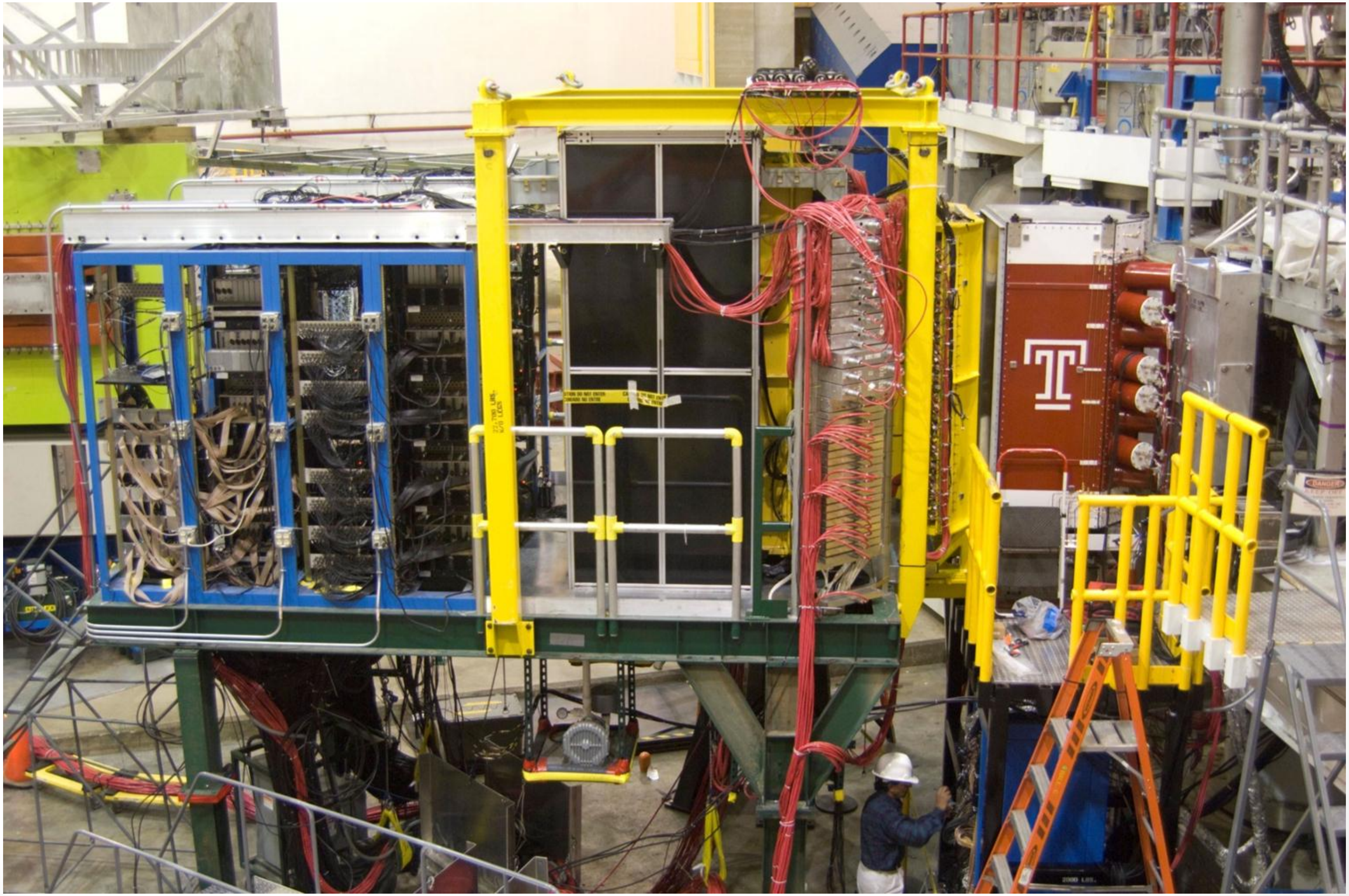


Big Electron Telescope Array - BETA

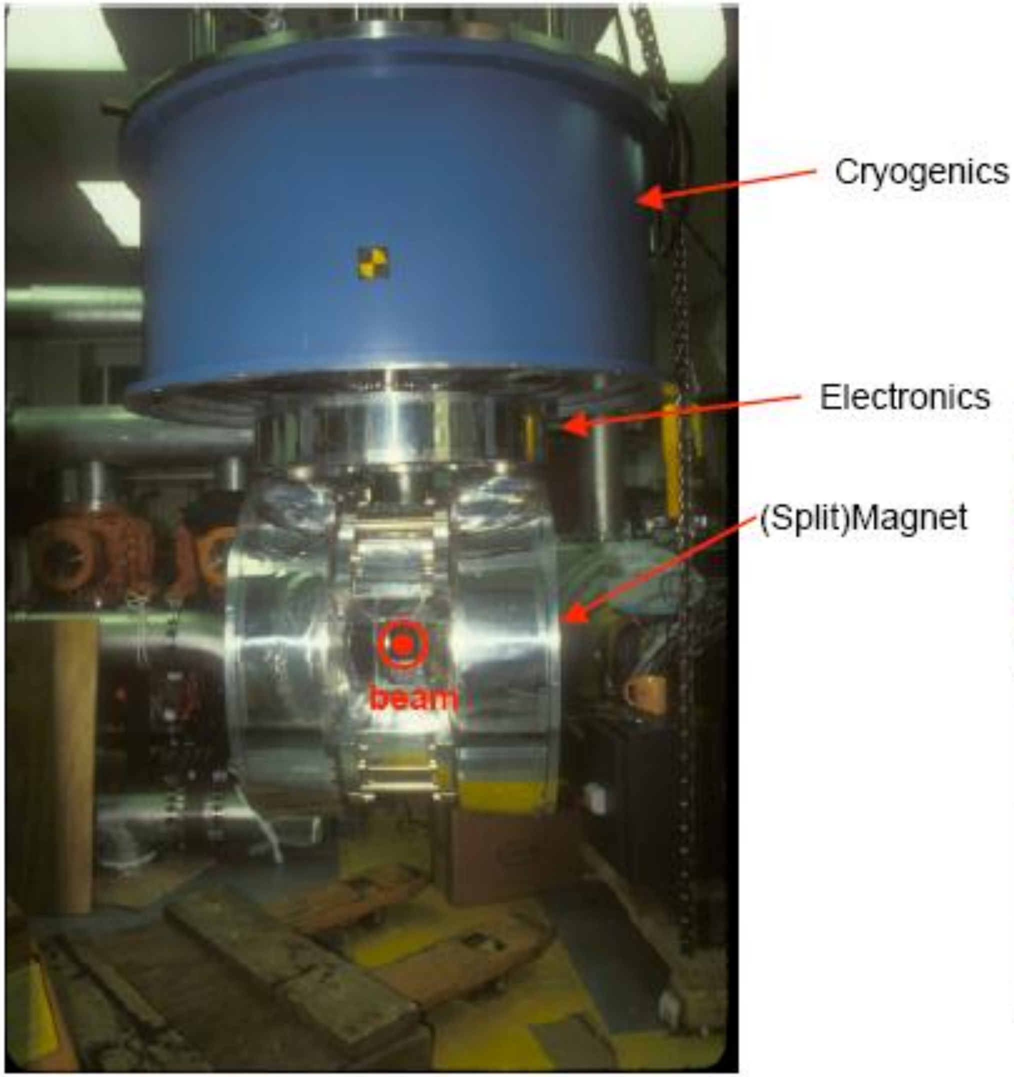
- BigCal lead glass calorimeter: main detector, being built for *GEp-III*.
- **Gas Cherenkov**: additional pion rejection
- Tracking **Lucite hodoscope**
- BETA's characteristics
  - Effective solid angle = 0.194 sr
  - Energy resolution $5\%/\sqrt{E}$(GeV)
  - angular resolution < 0.8°
  - 1000:1 pion rejection
- Added: **forward hodoscope**
  - vertex resolution ~ 5 mm
  - angular resolution ~ 1 mr
- Target field sweeps low *E* background

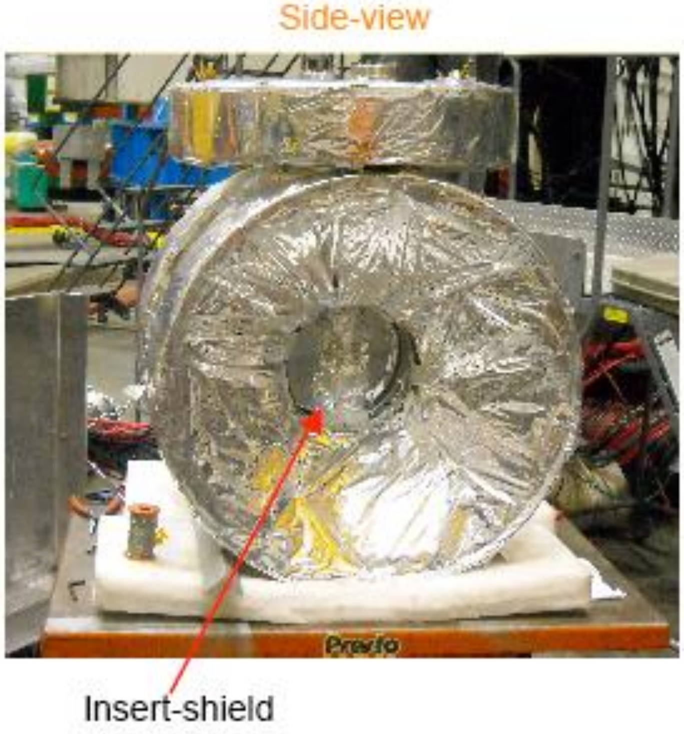


BETA

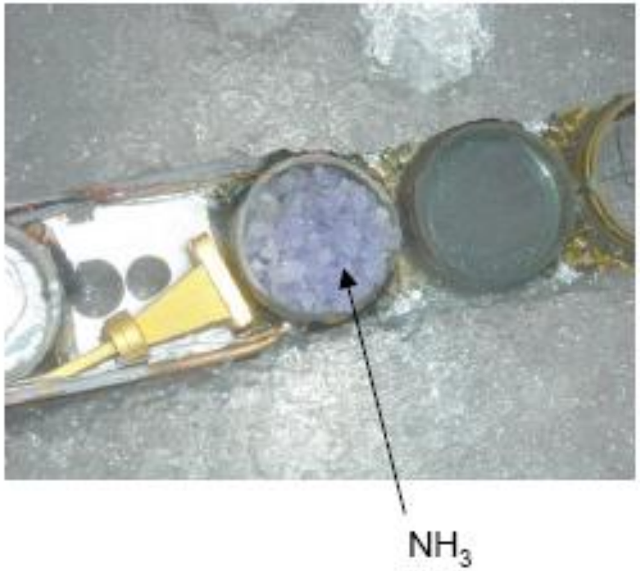


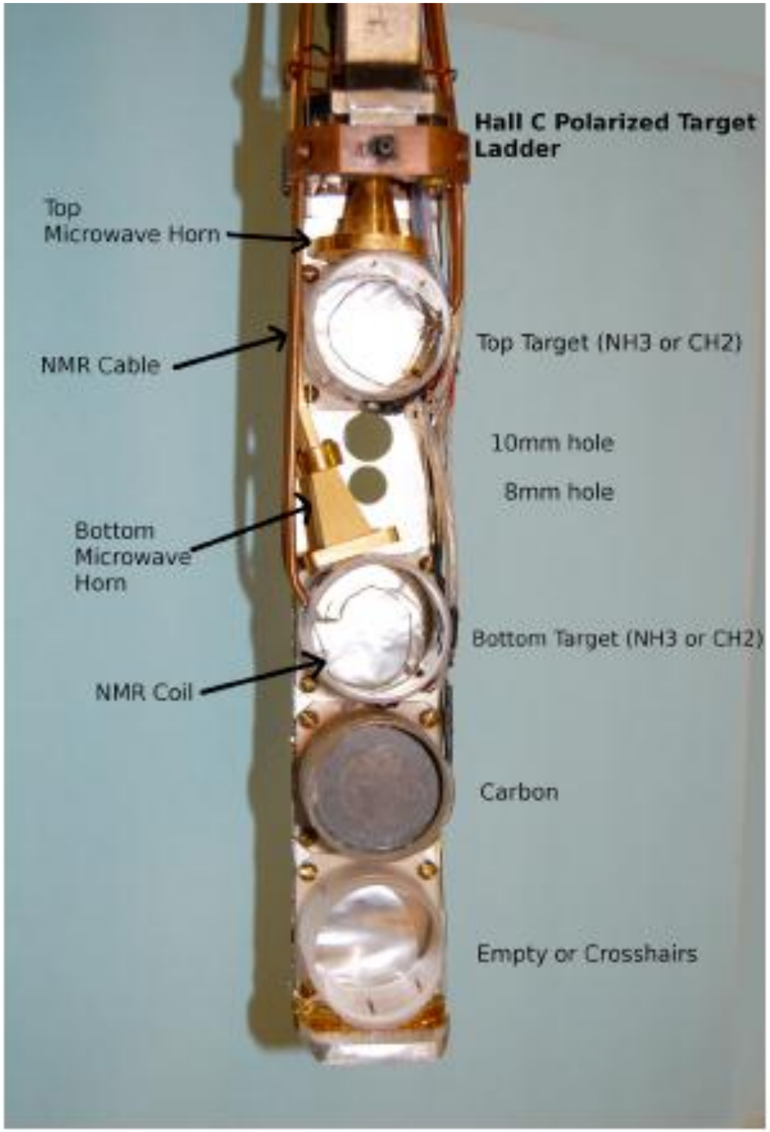
Target magnet





Target insert





Packing fraction

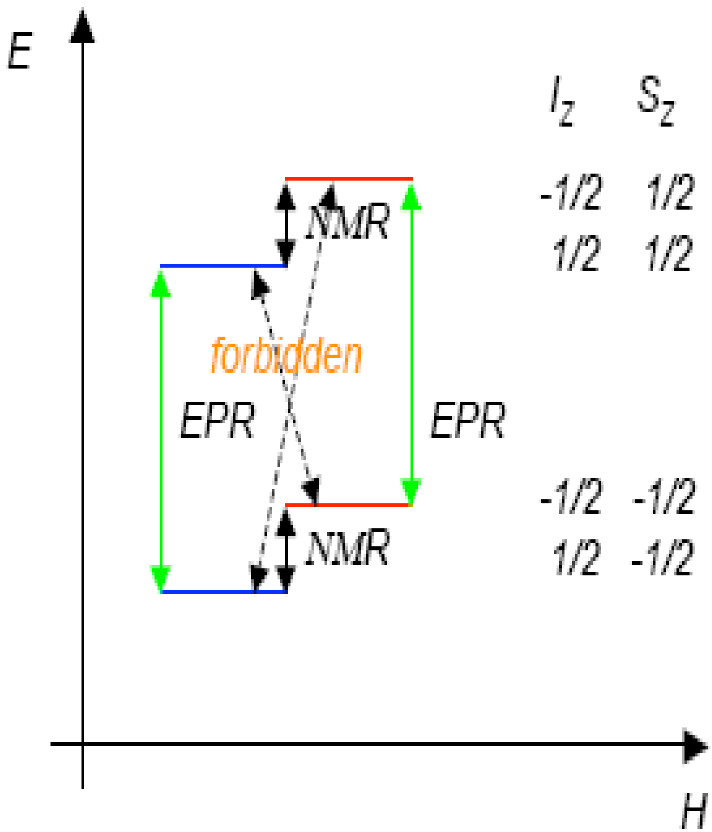
Material	PF(%)	Error(%p)
#2 JW 12/05 14NH3	61.0	4.32
14NH3 #13	60.7	4.22
#5 6-28-07 14NH3	59.6	4.47
#7 6-29-07 14NH3	59.6	4.47
#8 & 5 6-2x-07 14NH3	59.0	4.95
#5 & 6 6-2x-07 14NH3	56.9	4.74
#3 6/28/07 NIST irrad 14NH3	58.6	4.12
#2 6/28/07 NIST irrad 14NH3	58.8	4.34
#9 6-28-07 14NH3	61.9	4.59
#10 6-29-07 14NH3	59.4	4.44

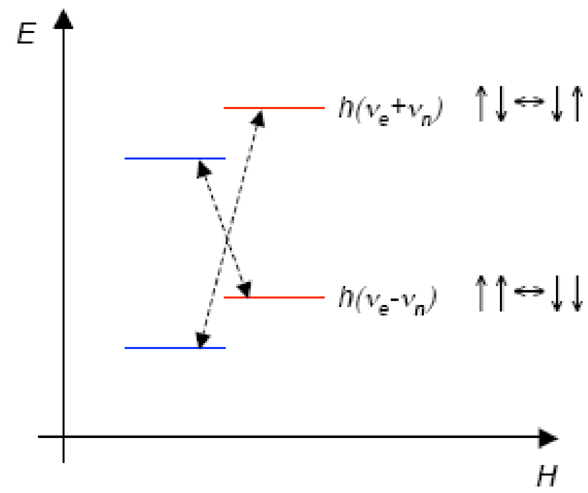
Dynamic Nuclear Polarization

The DNP process for polarizing protons, deuterons, or any nucleus possessing a magnetic moment, requires temperatures of ;1 K or less and large magnetic holding fields. For thermal equilibrium at 1 K and 5 T, the proton polarization is only about 0.5%. However, the polarization of the “free” electrons, associated with the paramagnetic radicals introduced into the target material, is greater than 99%. The electron polarization can be transferred to the proton through a hyperfine transition by irradiating the target with microwaves at appropriate frequencies.

K. Abe et al., Physical Review D 58, 11203 (1998)

Dynamic Nuclear Polarization





The rf field drives the forbidden transitions.

flip-flops: ↑↓↔↑↓

flip-flips: ↑↑↔↓↓

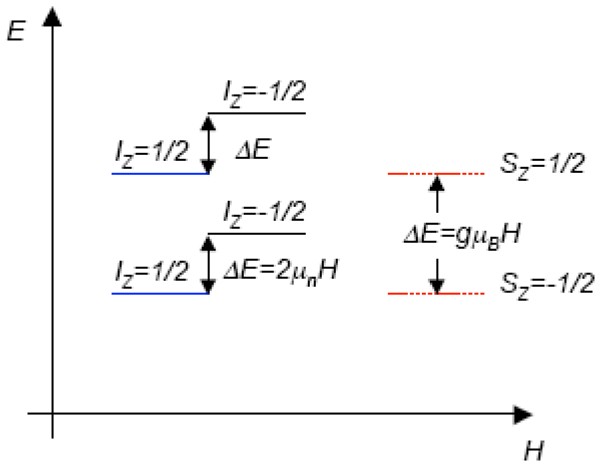
$\Delta(S_Z+I_Z) = 0,2$

Dynamic Nuclear Polarization

Nucleons also possess magnetic moment, although:

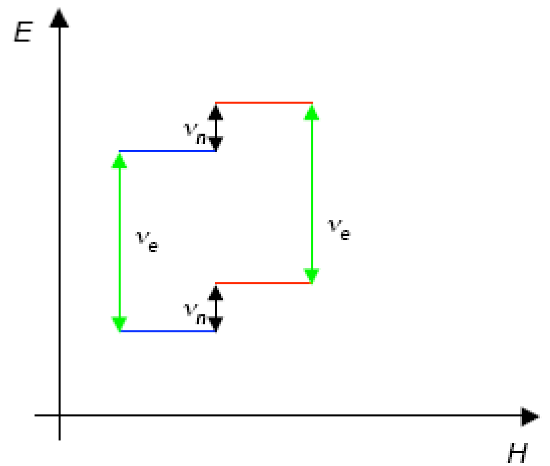
Nuclear moments/Electron Moments ~ 10^{-3}

Including nuclear moments => Hyperfine Splitting



S_z: Electrons

I_z: Nucleons, Nuclei



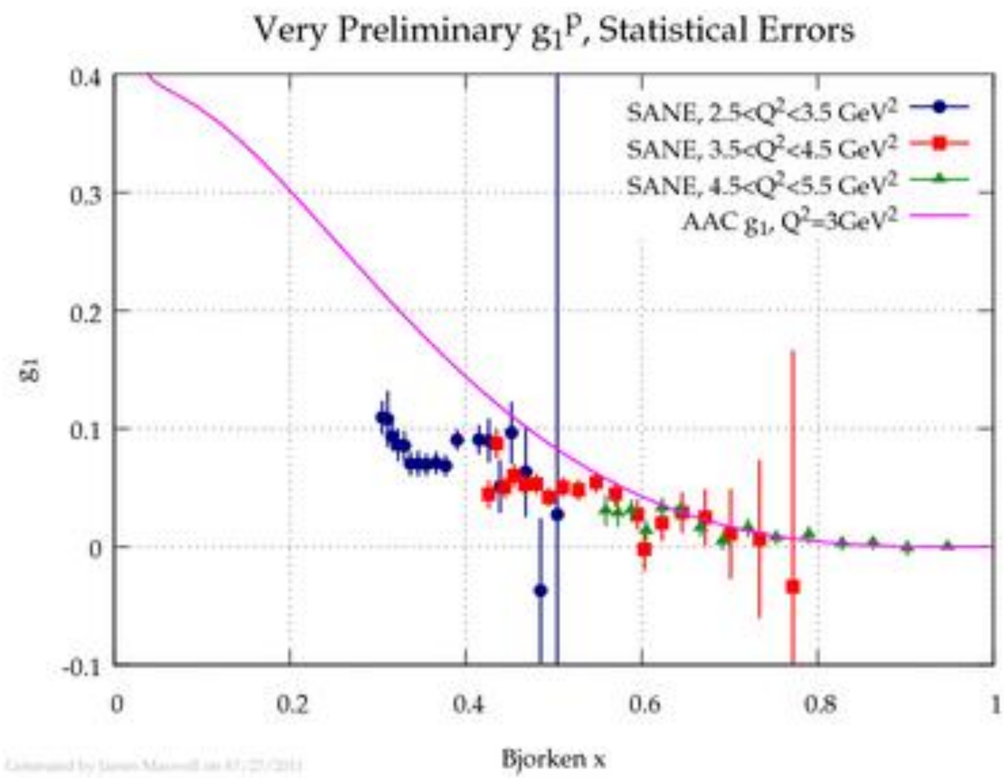
1) $\nu_{rf} \sim \nu_e$ get transitions -- -> -+
++ -> +-

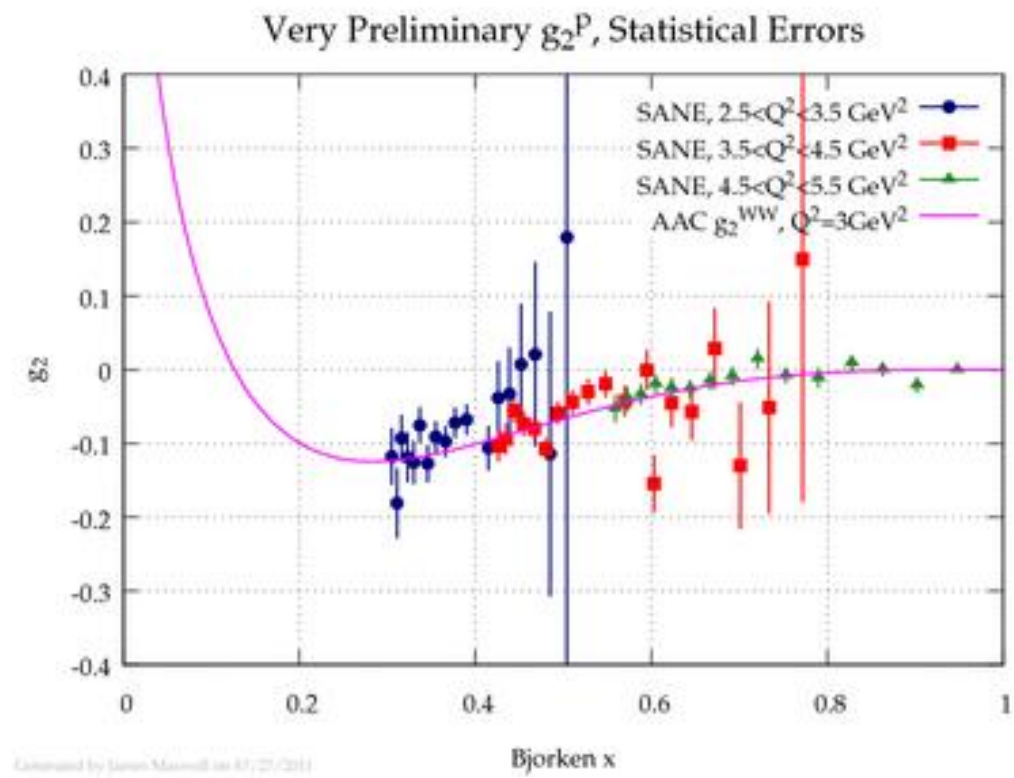
where $\Delta E = g\mu_B H = h\nu_e$

2) $\nu_{rf} \sim \nu_n$ get transitions +- -> ++
++ -> -+

where $\Delta E = 2\mu_n H = h\nu_n$

Preliminary g_1 and g_2 from BETA





J. Maxwell (UVA)

Borrwed Slides

Transverse Spin Structure Function

- Polarized longitudinal structure function has simple parton model interpretation

$$g_1(x) = \sum e_i^2 \Delta q_i(x), \quad i = u, \bar{u}, d, \bar{d} \ldots$$

- g_2 is combination of twist-2 and twist-3 components:

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \overline{g_2}(x,Q^2)$$

$$= -g_1(x,Q^2) + \int_x^1 g_1(x',Q^2)\frac{dx'}{x'} - \int_x^1 \frac{\partial}{\partial x'}\left[\frac{m}{M} h_T(x',Q^2) + \xi(x',Q^2)\right]\frac{dx'}{x'}$$

  - *W*andzura-*W*ilczek g_2^{WW} depends on g_1; h_T is twist-2 chiral odd transversity
  - ξ represents quark-gluon correlations (twist-3).

- Transverse spin structure function g_T measures spin distribution normal to virtual γ

$$g_T = g_1 + g_2 = \int_x^1 \left[g_1 - \frac{\partial}{\partial x'}\left(\frac{m}{M} h_T + \xi\right)\right]\frac{dx'}{x'} = \frac{\nu}{\sqrt{Q^2}} F_1(x,Q^2) A_2(x,Q^2)$$

Borrowed Slides

Transverse Spin Structure Sum Rules

- OPE: moments of g_1, g_2 related to twist-2 (a_N), twist-3 (d_N) matrix elements.

$$\int_0^1 x^N g_1(x,Q^2)\,dx = \frac{1}{2} a_N + O(M^2/Q^2), \qquad N = 0, 2, 4, \ldots$$

$$\int_0^1 x^N g_2(x,Q^2)\,dx = \frac{N}{2(N+1)}(d_N - a_N) + O(M^2/Q^2), \quad N = 2, 4, \ldots$$

- d_N measure twist-3 contributions (related to for $m \ll M$ and h_T not too large.)

$$d_N(Q^2) = \frac{2(N+1)}{N} \int_0^1 x^N \overline{g}_2(x,Q^2)\,dx$$

- Burkhardt-Cottingham $\int_0^1 g_2(x)\,dx = 0$
  - not from OPE
- Efremov-Leader-Teryaev $\int_0^1 x(g_1^V(x) + 2g_2^V(x))\,dx = 0$
  - valence quarks combining with $g_{2,1}^n$ from Hall A